RESEARCH

UDOT Keeping Utah Moving

Utah Department of Transportation - Research Division
4501 South 2700 West - P.O. Box 148410 - SLC,UT 84114-8410

Report No. UT-19.20

NON-OPTIMAL USAGE AND PERCEPTION OF A PROTECTED INTERSECTION FOR BICYCLING AND WALKING, SALT LAKE CITY, UT

Prepared For:

Utah Department of Transportation
Research & Innovation Division

Submitted By:

University of Utah
Department of City and Metropolitan Planning

Authored By:

Torrey Lyons
Dong-ah Choi
S. Hassan Ameli
Keunhyun Park
Reid Ewing

Final Report
Nov 2019

DISCLAIMER

The authors alone are responsible for the preparation and accuracy of the information, data, analysis, discussions, recommendations, and conclusions presented herein. The contents do not necessarily reflect the views, opinions, endorsements, or policies of the Utah Department of Transportation or the U.S. Department of Transportation. The Utah Department of Transportation makes no representation or warranty of any kind, and assumes no liability therefore.

ACKNOWLEDGMENTS

The authors acknowledge the Utah Department of Transportation (UDOT) for funding this research, and the following individuals from UDOT on the Technical Advisory Committee for helping to guide the research:

- Travis Jensen, WCEC Engineers
- Tom Millar, Salt Lake City Transportation
- Jamie Mackey, UDOT Traffic Operations
- Peter Jager, UDOT Traffic Operations
- Heidi Goedhart, UDOT Planning
- Jesse Sweeten, UDOT Traffic & Safety

TECHNICAL REPORT ABSTRACT

1. Report No. UT- 19.20	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle NON-OPTIMAL USAGE AND PERCEPTION OF A PROTECTED INTERSECTION FOR BICYCLING AND WALKING, SALT LAKE CITY, UT		5. Report Date November 2019 6. Performing Organization Code
7. Author(s) Torrey Lyons, Dong-ah Choi, S. Hassan Ameli, Keunhyun Park, and Reid Ewing		8. Performing Organization Report No. N/A
9. Performing Organization Name and Address University of Utah Department of City and Metropolitan Planning 375 South 1530 East, Suite 220 Salt Lake City, Utah 84112		10. Work Unit No. 55033 01D 11. Contract or Grant No. 19-8082
12. Sponsoring Agency Name and Address Utah Department of Transportation 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410		13. Type of Report & Period Covered Final Jul 2018 to Nov 2019 14. Sponsoring Agency Code UT17.309
15. Supplementary Notes Prepared in cooperation with the Utah Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration		

16. Abstract

This paper examines a before-and-after case study of a protected intersection in Salt Lake City, Utah. The intersection was completed in late 2015 and represents one of the first examples of a protected intersection in North America. This research aims to determine the impact of new intersection configurations on separated bike lanes in regard to perceived safety, ridership, and travel behavior. This study showed that there was little change in the use of people walking and bicycling after the implementation of a protected intersection in Salt Lake City although there was significant growth in scooter usage attributable to the introduction of shared e-scooter systems. Also, many non-optimal behaviors were reduced after the new configuration was deployed, including bicyclists crossing in the crosswalk, bicyclists crossing in streets, bicyclists stopping in the wrong place, and pedestrians stopping in the wrong place. The interview results showed that businesses expressed a relatively favorable perception of the protected intersection in both pre- and post-implementation periods while there were concerns about design elements, educating users about the appropriate ways to use the intersection, and the interaction between different active modes of transportation. This case study gives some evidence that a protected intersection can have positive effects on active transportation behaviors, and perceived safety in a U.S. context.

17. Key Words Protected Intersection, Bicycle, Pedestrian, Safety, Active Transportation, E-scooter, Salt Lake City		18. Distribution Statement Not restricted. Available through: UDOT Research Division 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410 www.udot.utah.gov/go/research		23. Registrant's Seal N/A
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 688	22. Price N/A	

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

NACTO	National Association of City Transportation Officials
LBI	Leading Bicycle Interval
LPI	Leading Pedestrian Interval
NACTO	National Association of City Transportation Officials
UDOT	Utah Department of Transportation

EXECUTIVE SUMMARY

This report examines a before-and-after case study of a protected intersection in Salt Lake City, Utah. The intersection was completed in late 2015 and represents one of the first examples of a protected intersection in North America. Key geometric design features of a protected intersection include (Falbo, 2014):

- *A corner refuge island bringing the protected barrier from the bike lane far into the intersection and separating people bicycling as they make right turns*
- *A forward stop bar for people bicycling creating a bicycle waiting area farther ahead in the intersection so that they are visible to drivers waiting at a red light and can make an effective head start when the light turns green*
- *A set-back bike and pedestrian crossing providing the space and time for everyone to react to potential conflicts*[1]

Protected intersections for people bicycling are a relatively new concept in North America, and thus, do not have a succinct, broadly accepted definition.

This research aims to determine the impact of new intersection configurations on separated bike lanes in regard to travel behavior, perceived safety, and ridership. First, we identified change in ridership of separated bike lanes from pre- and post-treatment by reviewing video footage captured from the same vantage point before and after intersection treatment. Second, we examined change in the rates of non-optimal behaviors of people walking and bicycling. This was also determined by comparing before- and after-implementation video footage and quantifying the conflicts that occurred at the intersection. For the first two tasks in this report, automobile data (which is critical to determining the safety of a protected intersection) was not included because of the limitations of observation method and poor data reliability. This is a critical caveat and is why this study focuses on behavioral, and not safety, analysis. Lastly, we assessed business perception of the protected intersection. A before-and-after survey was conducted to determine if there was any change in the perception of the protected intersection.

[1] Bicycle-friendly signal phasing is also recommended in the Falbo (2014) design features but was not implemented in the Salt Lake City protected intersection.

We found that after the implementation of a new protected intersection configuration, active transportation usage increased slightly through our three-year study period from 2015 to 2018. Increases in active transportation usage during this time, however, were mostly attributable to a rapid spike in e-scooter users. We also analyzed the rates of non-optimal behaviors at the protected intersection, determining how the frequency of these behaviors changed with the implementation of the protected intersection. We observed that the behavior of people walking shows a slight change in response to the new configuration: Higher rates of people walking were observed staying within the confines of the crosswalk while crossing. More noticeably, the behavior of people bicycling responded to the new infrastructure with reductions in people bicycling through the intersection within the pedestrian crosswalk, stopping on sidewalks and in the street, and making exposed vehicular-style left turns from the left-turn lane in the roadway. The reduction of these non-optimal behaviors suggests a positive effect on perceived safety for people bicycling and walking after implementation of the protected intersection.

Conversely, people bicycling tend to cross against the signal at higher rates with the new configuration. A new user type in the protected intersection space, post-implementation, is the e-scooter rider. These riders demonstrate much higher rates of non-optimal behaviors than both people walking and people bicycling. They are more likely to perform all non-optimal behaviors than their counterparts on two feet or bicycles except for making exposed crossings. E-scooter users utilize the sidewalk at an exceptionally high rate when compared to people bicycling, with 43% of all scooter users preferring this space.

Our qualitative analysis shows that businesses express a relatively favorable perception of the protected intersection in pre- and post-implementation periods. Ongoing concerns about the intersection were related to specific design elements, educating users about the appropriate ways to use the intersection, and the interaction between different active modes of transportation. Concerns that many businesses expressed prior to the implementation of the intersection, namely reduced parking and increased congestion, did not seem to remain important factors in the post-implementation period.

Generally, this study shows that active transportation use increased after the implementation of a protected intersection in Salt Lake City. Also, many non-optimal behaviors were reduced after the new configuration was deployed. This case study gives some evidence that a protected intersection can have positive effects on active transportation volume, compliance with optimal movements, and perceived safety in a U.S. context. However, we must note that this case study does not assert causality related to the observed changes in volumes and behaviors. Although the before-and-after nature of our samples might be a type of a quasi-experimental design, the small number of samples—three observation days—limits both the internal validity and external validity of our findings. More data and analysis are necessary to begin to make more concrete assertions about the relationships between active transportation volumes, behaviors related to perceived safety, and protected intersection configurations.

1.0 INTRODUCTION

1.1 Problem Statement

With the advent of new methods for safely integrating active transportation with otherwise automobile-dominated roadways, it is important to determine if these methods are, in fact, having their intended effects. Salt Lake City, Utah was one of the first municipalities in the U.S. to implement a protected intersection for bicycles. These intersections are a relatively new concept in North America, and thus, do not have a succinct, broadly accepted definition. However, Falbo (2014) highlights some key geometric design features that include:

- *A corner refuge island bringing the protected barrier from the bike lane far into the intersection and separating people bicycling as they make right turns*
- *A forward stop bar for people bicycling creating a bicycle waiting area farther ahead in the intersection so that they are visible to drivers waiting at a red light and can make an effective head start when the light turns green*
- *A set-back bike and pedestrian crossing providing the space and time for everyone to react to potential conflicts*[2]

This treatment was installed at the intersection of two separated bike lanes (also known as protected bike lanes or cycle tracks) in the heart of downtown Salt Lake City. Optimal behavior can be measured in many ways, however, for this study it is operationalized as people bicycling and walking who conform to the expected use of given lanes at the protected intersection and thus prevent possible conflicts. It can be assumed that if road users are changing their behavior to a higher degree of conformity to the expected optimal behaviors, the study area will be a safer place for non-automobile users.

Additionally, if the protected intersection demonstrates improved perceived safety, a case study of its implementation will be useful to transportation planners interested in constructing similar intersections. In order to collect feedback from the business community, some members of which were concerned about how a reduction in the availability of on-street parking might affect their bottom line, a survey was conducted to evaluate the perception of the protected intersection prior to its implementation. A similar survey was administered again as part of this

[2] Bicycle-friendly signal phasing is also recommended in the Falbo (2014) design features but was not implemented in the Salt Lake City protected intersection.

study to determine if there had been a change in perception. Understanding how perceptions change after the implementation of novel bicycle infrastructure will help planners and policy makers to put community responses into perspective. While there will always be some degree of resistance to change, if planners have a meaningful case study that documents how stakeholders respond to proposed intersection treatments, they can respond to stakeholders appropriately.

1.2 Objectives

This research aims to determine the impact of new intersection configurations on separated bike lanes in regard to ridership, perceived safety, and travel behavior.

Objective 1: Determine change in use of separated bike lanes from pre- and post-treatment. This was done using video footage captured from the same vantage point before and after intersection treatment.

Objective 2: Determine change in the rates of non-optimal behaviors of people walking, bicycling, and riding scooters, skateboards, and other similar devices. This was also determined by comparing before- and after-implementation video footage and quantifying the behaviors occurring at the intersection.[3]

Objective 3: Assess business perception of the protected intersection. A before-and-after survey was conducted to determine if there is any change in the perception of the protected intersection.

1.3 Scope

The above objectives were accomplished through a phased approach. The following major tasks were completed for each of the phases:

Task 1. Data Collection

[3] For Objectives 1 and 2, we did not include automobile data because of the limitations of observation method and poor data reliability.

Task 1A: Pre-Implementation Data Collection and Analysis

In order to measure the effects of protected intersection implementation, it was first necessary to assess the conditions at the intersection before the treatment. Two different types of data were collected: video footage of travel behavior at the intersection, and survey data of local business, which are mostly restaurant owners and managers. Video footage was taken of the intersection from an elevated vantage point to the southeast. This video footage was used to evaluate two important criteria being measured in this study: ridership of the two streets' separated bike lanes, and deviance from optimal usage of the walking and bicycling facilities. The survey data were collected in January 2015, before the protected intersection was constructed, but after the decision had been made to implement it. Local business owners were the recipients of the survey, and questions were asked about their general attitudes towards the new infrastructure, their concerns, and how they expected the intersection to affect them in the future.

Task 1B: Post-Implementation Data Collection and Analysis

Post-implementation data collection closely mirrored the methods used for pre-implementation collection. Video footage was recorded from the same vantage point to allow for easy pre- and post-treatment analysis. The video was collected on two fair-weather weekdays in the summer, recorded from 7 a.m. to 7 p.m. Night-time footage was not captured due to video equipment limitations.

The post-implementation survey was administered to three of the eight participants that were included in the pre-implementation stage. The same questions that were asked in the pre-implementation survey were asked again, with additional questions added based on common concerns from the original survey, as well as questions that are only applicable to post-implementation conditions.

Task 2. Literature Review

A literature review was conducted to inform the researchers as well as funders of the study of the current state of research on protected intersections. The literature review primarily focused on studies conducted in the U.S., however insights from abroad were included as well, given the limited number of protected intersections in existence in the U.S., and the limited time that researchers have had to study them.

Task 3. Data Analysis

Task 3A. Video Review

Video footage was reviewed for two purposes: determining changes in ridership of active transportation modes, and assessing changes in optimal usage of the intersection. The number of people bicycling, walking, and riding scooters, skateboards, and other similar devices were counted hourly. The ridership figures were tallied on an hourly basis in order to better understand how peak demand for the intersection varied between modes of travel.

Video footage was also analyzed to determine the degree of deviance from optimal usage of the intersections. Undesired behavior was operationalized by identifying expected non-optimal behaviors at the protected intersection. Quantified non-optimal uses included bicycling or walking in the street (outside the separated bike lanes) or on the sidewalk, bicycling in the wrong direction, disobeying a traffic signal (person bicycling or walking), stopping in the wrong location, and walking in the separated bike lanes. Some of these non-optimal uses were not possible during the pre-implementation stage, thus there were no observed changes in such behavior.

A database was compiled to document occurrences of non-optimal behavior, separated bike-lane ridership, and non-motorized traffic by time. Statistical analyses were also conducted, including reliability tests and descriptive statistics.

There was a limitation in this video review. Although automobiles are an important travel mode to consider when determining the safety of a protected intersection, we did not include this mode because of the limitations of observation method using video data and poor data reliability, compared to the other data. As a result, the analysis presented in this report only informs active transportation behavior and perceptions of active transportation safety. The study design is not capable of informing conclusions about safety itself.

Task 3B. Survey Data Analysis

Survey data were analyzed using descriptive statistics of quantifiable survey responses as well as qualitative analysis of non-quantifiable responses.

Task 4. Case Study Interviewing

In order to develop a more in-depth case study, three local business owners or managers were interviewed. These interviews dove deeper than the survey questions to better understand how business owners perceive the protected intersection and how they believe the infrastructure has affected their businesses before, during, and after the construction of the intersection. Researchers asked participants about concerns over parking, traffic, and other frequently-raised issues from the initial pre-implementation survey. These interviews added a layer of nuance to our qualitative data, allowing us to triangulate the results of the qualitative inquiry.

1.4 Outline of Report

This report includes the following contents:

- Introduction
- Background
- Literature Review
- Protected Bicycle Infrastructure Design
- Methodology
- Results
- Conclusions
- References

2.0 BACKGROUND

As researchers and planners begin to realize the challenges related to an automobile-dominated transportation paradigm, they have looked to their peers in Europe for ideas and guidance. Certain forces have allowed European cities to create built environments that are more conducive to multimodal transportation, and therefore many of the best examples of active transportation policy and infrastructure exist there. Leading researchers in bicycling and walking planning have written at length about the lessons that can be learned from European traffic designs, and practitioners have adapted those designs to conform to an American context. A fair amount is known about the effects of these traffic configurations from studies that have examined European examples empirically, however, it cannot necessarily be assumed that these findings are generalizable to a North American context. Korve & Niemeier (2002) suggest that differences in policy, infrastructure, mode share, and even attitudes of people driving and people bicycling between European and U.S. cities could affect how insights from existing research should be interpreted by local planners.

Protected intersections in North America have incorporated many attributes of successful European designs. These designs often physically separate rights of way, make people walking and people bicycling more visible to drivers, provide shorter crossing distances for active transportation users, and prioritize active modes through signalization. These intersection treatments are relatively new to North American cities, and their effects have been minimally studied (Weigand, 2008). Out of the handful of protected intersections that currently exist in North America, Salt Lake City's is the best example of one that incorporates the most aspects of the adapted North American typology. This premier example, along with the foresight to collect video data of the intersection before the new configuration was implemented, creates fertile ground for research. This study uses before-and-after video analysis to determine the effects of a protected intersection on perceived safety and usage by people walking and bicycling. This study is the first of its kind for a U.S. protected intersection, and its insights will help to guide active transportation infrastructure design and implementation in the future.

3.0 LITERATURE REVIEW

When active transportation planning first came to the fore in North America, planners looked to European cities for insight into how to create more hospitable environments for people walking and bicycling. Policies that can help make active transportation more appealing than automobiles often include gasoline or carbon taxes, high registration fees for vehicles, and other economic disincentives (Jakobsson, 2004; Low, 1995). Such policies, however, might be considered untenable within the current context of American politics. If the stick is not a viable option for U.S. planners and policy makers, what about the carrot? Pucher and Buehler (2008) looked to European examples, and found that beyond automobile-restricting policies, countries like the Netherlands, Denmark, and Germany relied on ubiquitous provision of better infrastructure for people bicycling and walking in order to enhance the attractiveness of these modes. European cities have long provided for integration of people bicycling and driving through the use of special signalization, physical separation, advanced stop location for people bicycling, and other designs that facilitate safe use of streets among multiple modes of transportation (Godefrooij, 1997). Researchers have found that physical separation of automobile and bicycle rights-of-way can improve the perceived safety of active transportation, and lead to increased usage (Cervero, Caldwell, & Cuellar, 2013; Macmillan et al., 2013; Pucher & Buehler, 2008). Additionally, the benefits of investment in active transportation infrastructure have been shown to far exceed the costs. Gotschi (2011) found that $605 million of bicycle investments in Portland, OR would result in health-care savings of $594 million, fuel savings of $218 million, and value of statistical lives of $12 billion over a 50-year period.

Through the addition of new infrastructure and a general increase in attention given to active transportation in the past few decades in the U.S., total bicycle trips have increased significantly (Pucher, Dill, & Handy, 2010; Pucher et al., 1999). While this represents a terrific realization of the efforts of planners to enhance the environment for active transportation, it also presents a new opportunity for increased conflicts between people bicycling, walking, and driving. Motor vehicles, on their own, can be dangerous, with motor vehicle collisions being a leading cause of death globally, and among the top-ten-most-prominent causes of death among young people nationally (Murray & Lopez, 1997; Webb, 2018). The best estimates of pedestrian-vehicle crashes suggest that there are more than 100,000 of these types of incidents per year in the U.S., with nearly 5,000 of them being fatal (Glassbrenner, 2002; NEISS, 2002). Although there is always potential for conflict between automobiles and people walking and bicycling, the likelihood of a collision is far greater at intersections, where all modes interact using much of the same space (Korve & Niemeier, 2002; Watchel & Lewiston, 1994; Wang & Nihan, 2004). In fact, a study of 15 years of crash data in Palo Alto, CA found that nearly three quarters of crashes involving motor vehicles and people bicycling occurred at intersections (Watchel & Lewiston, 1994). For this reason, much of the literature on safe design for people bicycling and driving has focused on behavior at intersections (Chao et al., 1978; Opiela et al., 1980; Carter et al., 2006). There has also been a tendency to study crash history, as longitudinal data have some advantages in their ability to imply causation. Unfortunately, however, these studies are limited because their design necessitates decades worth of data (Hunter et al., 1997; Carter et al., 2006; Weigand, 2008).

Many design features have been developed in hopes of creating a safer environment for the interaction of vehicles and people walking and bicycling. The details of these elements of protected intersection design will be discussed in more detail in the design section of this report, but here we will highlight the findings of empirical studies that have tested the safety of different intersection safety treatments. Colored markings are one of the simplest and most cost-effective methods used for delineating the respective spaces for people bicycling and driving (Landis, Vattikuti, & Brannick, 1997). Colored markings through intersections demand even more attention from roadway users and have been shown to decrease intermodal crash rates in both European and American contexts (Jensen, 2007; Hunter, 2000). Bicycle boxes, or protected areas that allow people bicycling to safely enter and stop in an advanced position in an intersection in front of automobiles, allow people bicycling to be more visible to drivers. However, limited research has shown little empirical evidence for increased safety. Hunter (2000) finds little reduction in conflicts between motor vehicles and people bicycling, and a significant amount of encroachment into the bike box by vehicles.

New methods for traffic signalization have also been employed in an attempt to improve safety at intersections. Scramble signals allow people bicycling and walking to move freely in all directions while automobiles are restricted from entering the intersection. Bicycle-only directional signal phasing also restricts automobiles from entering the intersection while people bicycling are permitted. Both methods have been shown to improve safety of intersections by reducing the number of conflicts (Wolfe et al., 2006; Korve & Niemeier, 2002). Increases in intersection usage by active transportation modes have also been attributed to scramble signals (Wolfe et al., 2006).

Leading Pedestrian Intervals (LPI) and Leading Bicycle Intervals (LBI) typically give people walking and people bicycling a 3-7 second head start when entering an intersection with a corresponding green signal in the same direction of automobile travel. LPIs and LBIs enhance the visibility of people walking and bicycling in the intersection and reinforce their right-of-way over turning vehicles, especially in locations with a history of conflict. LPIs have been shown to reduce pedestrian-vehicle collisions as much as 60% at treated intersections.[4]

Finally, as these methods make intersections more appealing to active transportation users, simply the increased number of people walking and bicycling through the intersection may make the environment safer for those modes. Jacobsen (2003) found that motorists are less likely to collide with people walking and bicycling when more of these users are present.

Although the above findings help planners and traffic engineers to determine what treatments might more safely integrate all modes of transportation at intersections, there remains a significant amount of knowledge yet to be discovered. Many European cities like Copenhagen and Amsterdam have developed intricate systems of protected bicycle lanes and intersections that employ many of the methods we have discussed for creating safer intersections. However, studies of these intersections are limited in number, and confounding the situation further is the fact that findings from studies of European designs in European contexts might not be applicable in a North American context because of more active transportation-oriented development in Europe and car-oriented development in the U.S. Higher density in European cities could impact travel volume and street and sidewalk width. There is a dire need, then, for studies that examine the safety effects of protected intersection treatments in the U.S. This study examines the best American example of a protected intersection to date, using before and after video analysis of people walking, bicycling, driving, and using other transportation devices in the intersection.

[4] Source: https://nacto.org/publication/urban-street-design-guide/intersection-design-elements/traffic-signals/leading-pedestrian-interval/

4.0 PROTECTED BICYCLE INFRASTRUCTURE DESIGN

4.1 Overview

Providing multiple transportation modes has been recognized as an important strategy in transportation planning to serve diverse transportation demands. Bicycling became a popular transportation option in cities by allowing people bicycling to cover greater distances than walking and not requiring the costs associated with owning and operating a private vehicle. A recent study reveals that many European cities have fostered improved bicycling environments and culture. This is demonstrated by high bicycle mode shares, low fatal crash rates, more bike-specialized roads, and a better road surface quality (Coya, 2019). However, Coya (2019) also shows that cities in the U.S. lack such adequate infrastructure for bicycling and have marginal bike usage compared to cities in Europe, Asia, and other regions of the world (Figure 4.1).[5]

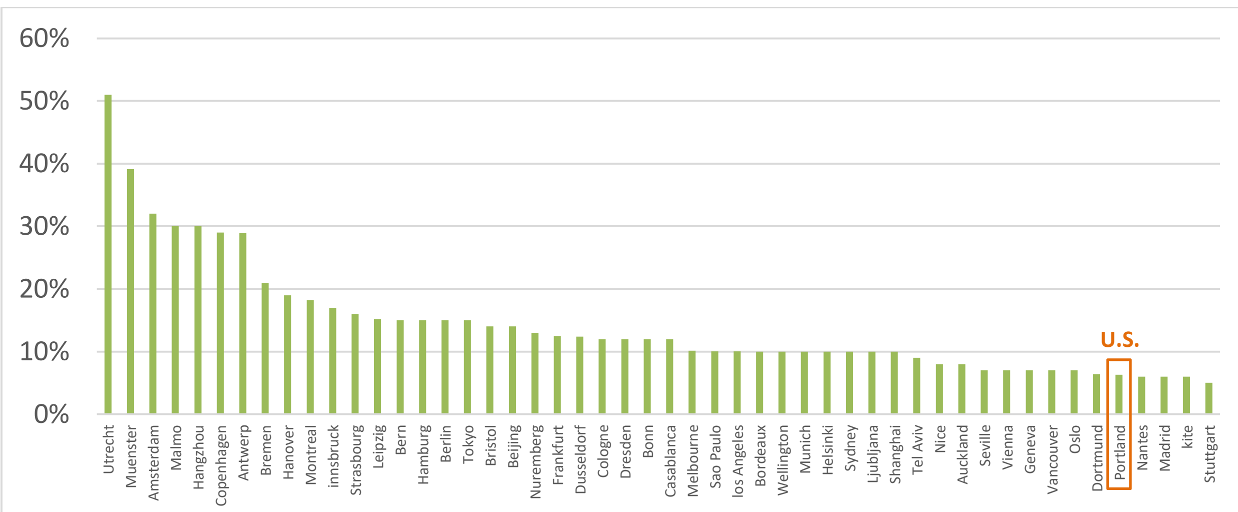

Figure 4.1 Top 50 Cities with the Highest Percentage of All Bicycle Usage

(Source: Coya Bicycle Cities Index 2019)

Safe and comfortable bicycle-specialized environments can be an important factor to facilitate bicycling in cities. Research on bike paths and lanes of 90 large American cities found

[5] Bike usage share in U.S. cities: Portland (6.3%), Washington, D.C. (4.6%), San Francisco (3.9%), Seattle (3.5%), Boston (2.4%), Chicago (1.7%), New York (1.2%), Los Angeles (1.1%), Detroit (1.0%) (source: Coya Bicycle Cities Index 2019)

that higher rates of bicycling to work are correlated with a higher number of bike paths and lanes (Buehler and Pucher, 2012). Moreover, Buehler and Dill (2015) reviewed literature on bikeway networks and revealed that intersection designs affect both the perceived and real safety of the routes of someone bicycling, also leading to how people bicycling decide which routes to take. Nevertheless, the authors pointed out that minimal studies have analyzed the post-effect of specific features of bicycle facilities or intersection treatments on bicycle use. Understanding bike-specialized intersection designs and how they have evolved will provide underpinning knowledge to analyze before-and-after changes in the case of Salt Lake City.

4.2 From Protected Bike Lane to Protected Intersection

Considering the increasing rate of bicycling, providing safe and convenient bike facilities is a growing focus for local and state governments. By providing more separation between bike and car lanes, protected bike lanes provide the highest level of perceived safety compared to painted bike lanes (McNeil, Monsere, and Dill, 2015). Perceived comfort increases significantly where buffers include some kind of physical protection. Different types of protected bike lane improvements provide a safer and more comfortable environment for bicycling. A team of researchers from Portland State University evaluated protected bike lanes in Austin, Chicago, Portland, San Francisco, and Washington, D.C. (Monsere et al., 2014). According to this study, ridership increased between 21% and 171% on facilities within one year of installation. Furthermore, based on the study, design with more physical separation has the highest effect on improving the comfort of people bicycling.

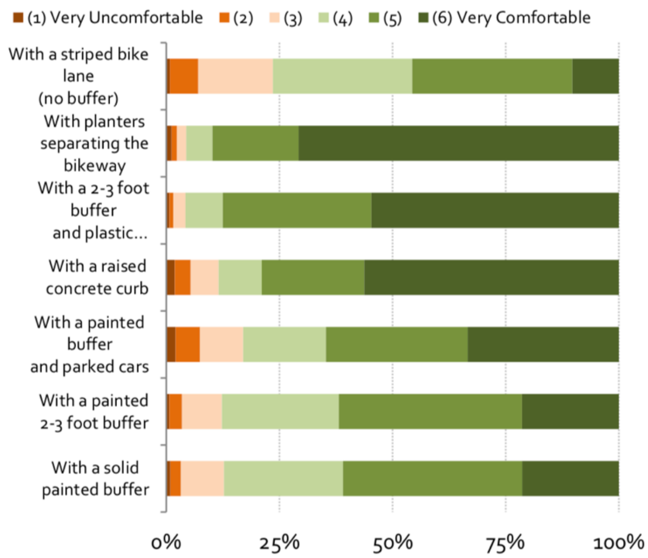

Figure 4.2 Stated Comfort Level of Persons Bicycling with Hypothetical Buffer Options
(Source: Monsere et al., 2014)

Monsere et al. (2014) also found that 96% of people bicycling and 79% of residents believe that the installation of protected bike lanes increased bicycling safety on the street. Additionally, they find that physically separated bike lanes induce usage from riders that might otherwise be too afraid to share space with vehicles and therefore have not yet been willing to ride in an urban environment.

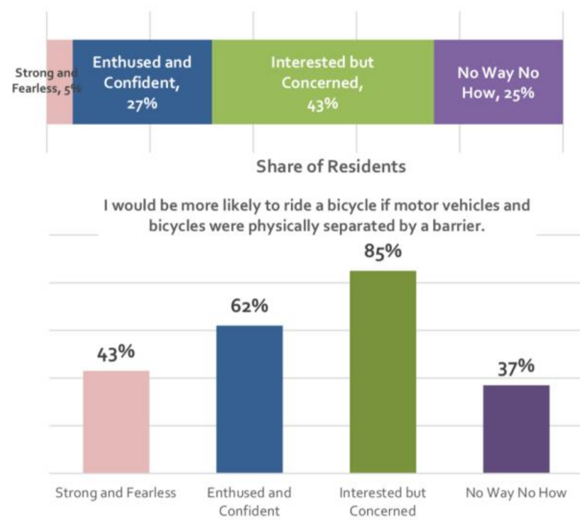

Figure 4.3 Residents' Likelihood of Riding with Physical Separation by Type of Person Bicycling (Source: Monsere et al., 2014)

Protected bike lanes are the best approach that practitioners have in their toolbox for addressing bicycling safety and comfort and to decrease the chance of collisions and fatalities. An issue that has not yet been sufficiently addressed, however, is that the benefits of protection disappear at intersections where the buffer between cars and people bicycling vanishes and a new point of conflict between these modes presents itself. This is where the need for protected intersections arises.

4.2.1 Brief History of Protected Bike Intersections in North America

The concept of protected intersections was first proposed in a manual in the 1970s in California. However, the idea was never built. Mark Wagenbuur, a Dutch writer, published a video to demonstrate his idea for a protected intersection as a response to the 2011 *Urban Bikeway Guide* published by the National Association of City Transportation Officials (NACTO). Wondering if the NACTO guide was really the best design that could be done, he proposed a new design for the U.S. that was already in use in Europe, called the "Dutch Junction," with a video demonstration of its advantages. Initially, his idea was not included in the NACTO guide because the Dutch Junction had not been implemented or proven. Despite not being included in the standard roadway design document, his idea became popular and has been promoted by active transportation planners and activists.

Figure 4.4 Dutch Bike Intersection Design Development (Source: Wagenbuur, 2011)

The video became popular and was distributed among active transportation planning professionals in Europe and the U.S. However, nothing happened on the ground level for a few years until Nick Falbo, an American urban planner and bikeway designer, and fan of Mark Wagenbuur, coined the phrase “protected intersection” with a video and online design guidance of his own. Next, Falbo sought a place to bring his design to life. He submitted his design to the City of Portland, but the city insisted that the design must be further adapted to a U.S. context. The next step was an effort to develop the Wagenbuur concept and evolve it to meet the U.S. context demands.

An integral component of bringing the design to fruition was defining the basic components of protected intersections (Falbo, 2014)

- Corner refuge island
- Set-back bicycle and pedestrian crossing
- Forward stop bar
- Bicycle-specific signal phasing

Next, based on these design features, an intersection in an auto-oriented neighborhood of the east side of Portland served as the basis for Falbo’s animated 6-minute video that demonstrated how this design could be implemented. The video was published in February 2014 and proliferated widely among active transportation planners and activists.

4.2.2 Corner Refuge Island

To extend the characteristics of the protected bike lane, the Dutch Junction design includes a protective island to create a buffered area. The corner refuge island provides separation between car lanes and bike lanes on all corners of the intersection. These curb extensions are intended to protect people walking as well. “The more you can separate fast-moving cars from the sidewalk, the more pleasant the experience is going to be for pedestrians,” Falbo said.

4.2.3 A Set-Back Bicycle and Pedestrian Crossing

The set-back crossing decreases anxiety at the intersection by adding a minimum of 6 meters of space between stopped vehicles and active transportation users. This provides wider and clearer sight distances for drivers to make sure the intersection is clear before turning. This also increases the potential reaction time to avoid any conflict. Finally, the small corner radius forces drivers to slow their turning speed to 5-10 mph.

4.2.4 Forward Stop Bar

A forward stop bar is paired with the corner refuge island. Drivers must stop behind the crosswalk while people bicycling can stop at the bicycle waiting area farther ahead. This makes people bicycling significantly more visible to drivers and greatly decreases the road crossing distance for people bicycling.

4.2.5 Bicycle-Friendly Signal Phasing

Bicycle-specific signal phasing is a tool to control the movements of different users in a way that further promotes visibility and priority of active transportation users. These signals separate car and bicycle movements to minimize the chances of conflict. There are two basic categories of protected bicycle signals: bicycle scramble signals that allow people bicycling to move through the intersection in all directions simultaneously, while automobiles are not allowed to enter the intersection; and directional-phased bicycle signals that allow people bicycling to enter the intersection from two directions at a time while prohibiting some automobile movements through the intersection.

Under the phasing scheme shown in Figure 4.5, right and left turns for cars are not allowed while people bicycling and walking are proceeding through the intersection. The bicycle and pedestrian crossings run only with the concurrent vehicular through phase. This offers the comfort of a protected signal phase, while still moving non-conflicting motor vehicles.

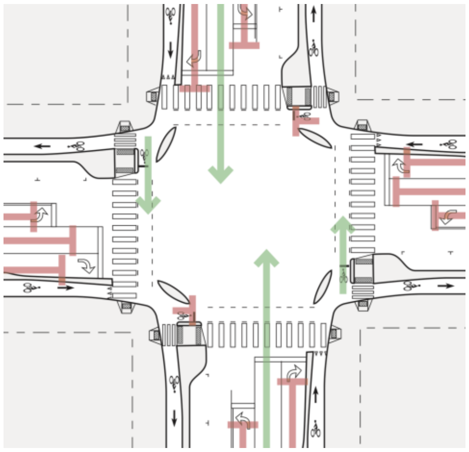

Figure 4.5 Bicycle-Friendly Signal Phasing, Protected but Concurrent Phasing

(Source: Alta Planning + Design, 2015)

The signal phasing approach displayed in Figure 4.6 offers people bicycling and walking protection from left-turning cars but allows permissive right turns for cars to occur concurrently with conflicting bicycling and walking through movements. This configuration is common practice today, with the underlying assumption that motorists must yield to people bicycling, who then must in turn yield to people on foot.

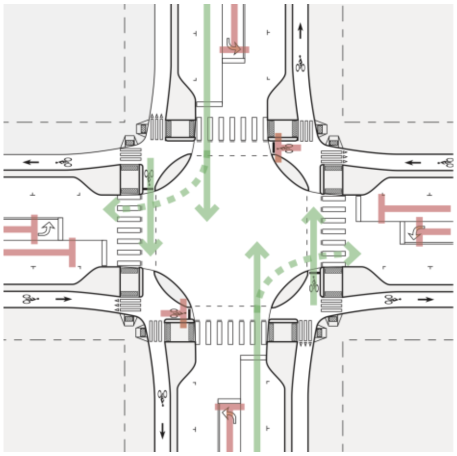

Figure 4.6 Bicycle-Friendly Signal Phasing, Protected Left-Turn Phasing

(Source: Alta Planning + Design, 2015)

Figure 4.7 illustrates another common phasing scenario. In this case, both left- and right-turning drivers yield to conflicting vehicle, bicycling, and walking traffic streams before completing the turn. While separated turn lanes may be provided, the turning movements are allowed concurrently with the through movement. This is the phasing present at the 300 South/200 West intersection in Salt Lake City.

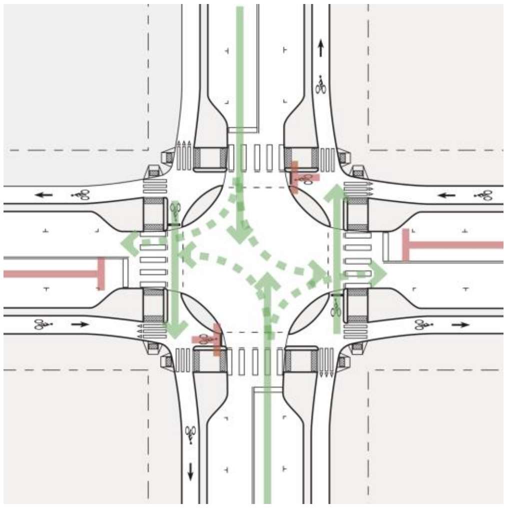

Figure 4.7 Bicycle-Friendly Signal Phasing, Permissive-Only Signal Phasing

(Source: Alta Planning + Design, 2015)

All-way bicycle and pedestrian phases offer an exclusive phase for non-motorized users in all directions at once. Permissive conflicts between people bicycling and walking are negotiated between users.

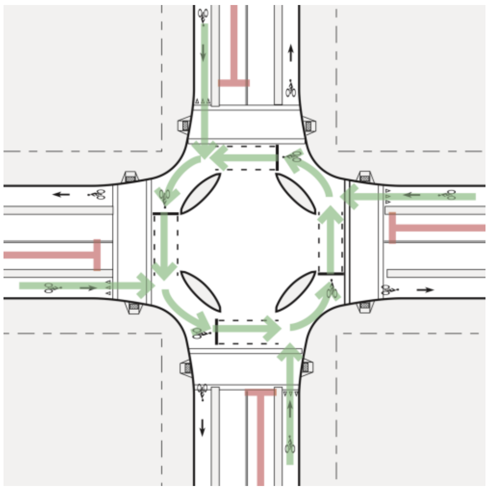

Figure 4.8 Bicycle-Friendly Signal Phasing, Exclusive All-Way Bicycle/Pedestrian Phasing

(Source: Alta Planning + Design, 2015)

4.3 Select North American Cities with Protected Intersections

As the Dutch Junction idea began to gain traction in the U.S., cities quickly tried to adapt it to their specific needs. Today, the protected intersection concept has been implemented in ten different locations in the U.S. and two in Canada. Below we display images and specifications of some of the premier examples.

4.3.1 Austin, Texas

Figure 4.9 Austin Protected Intersection (Source: Alta Planning + Design, 2015)

Location: Tilley and Zach Scott Streets
Street Type: Local streets
Street Context: Residential subdivision
Motor Vehicle Volumes: Unknown
Bikeway Type: Two-way protected bike lanes
Corner Refuge Island Outside Radius: 20 feet (6.0 meters)
Crossing Setback Distance: 14 feet (4.2 meters)

4.3.2 Davis, California

Figure 4.10 Davis Protected Intersection (Source: Alta Planning + Design, 2015)

Location: Cannery Avenue and East Covell Boulevard
Street Type: Arterial street at neighborhood collector
Street Context: Residential subdivision
Motor Vehicle Volumes: East Covell Boulevard, 20,000 ADT; Cannery Avenue, 3,500 ADT
Bikeway Type: On street bike lanes and bi-directional shared-use path
Corner Refuge Island Outside Radius: 36 feet (11 meters)
Setback Distance: 22-32 feet (6.7-9.7 meters)
Note: The Davis intersection allows two-way bicycle movements. Waiting areas for people bicycling and walking are not separated in this design.

4.3.3 Chicago, Illinois

Figure 4.11 Chicago Protected Intersection (Source: Alta Planning + Design, 2015)

Location: Washington and Franklin Streets
Street Type: Dedicated bus corridor; one-way streets
Street Context: Central business district
Motor Vehicle Volumes: Unknown
Bikeway Type: One-way separated bike lane with one-way buffered bike lane
Corner Refuge Island Outside Radius: 15 feet (4.5 meters) (approximate)
Crossing Setback Distance: 8 feet (2.4 meters)
Note: This intersection was constructed as part of the Loop Link bus rapid transit project.

4.3.4 Vancouver, British Columbia

Figure 4.12 Vancouver Protected Intersection (Source: Alta Planning + Design, 2015)

Location: Burrard Street and Cornwall Avenue
Street Type: Arterial and collector
Street Context: Bridge approach south of downtown
Motor Vehicle Volumes: Unknown
Bikeway Type: Two-way separated bike lane and one-way separated bike lane
Corner Refuge Island Outside Radius: 20 feet (6.0 meters) (approximate)
Crossing Setback Distance: 7 feet (2.1 meters)
Note: Conflicts are managed through protected signal phasing.

4.3.5 Montreal, Quebec

Figure 4.13 Montreal Protected Intersection (Source: Alta Planning + Design, 2015)

Location: Rue Cherrier and Rue Berri
Street Type: Local street and major arterial
Street Context: Residential neighborhood
Motor Vehicle Volumes: Unknown
Bikeway Type: Forced turn of a two-way separated bike lane
Corner Refuge Island Outside Radius: 20 feet (6.0 meters) (approximate)
Crossing Setback Distance: 6 feet (1.8 meters)
Note: Constructed out of planters and posts to allow for snow clearance.

4.3.6 Salt Lake City, Utah

Salt Lake City was the second city in the U.S. to install the protected intersection, months after Davis, California. Salt Lake City, with wide streets, has many opportunities to implement protected intersections. The location was chosen at the intersection of two streets with protected bike lanes either planned or in place. This protected intersection is the closest of any North American example to the original prototype idea put forward by Falbo. Dedicated bicycle signalization was dropped from the original design as a result of discussion with local planners, who determined that the design accomplished, geometrically, what some of the signalization options would have accomplished.

Figure 4.14 Salt Lake City Protected Intersection (Source: Alta Planning + Design, 2015)

Location: 200 West and 300 South Streets
Street Type: Minor collector
Street Context: Central Business District
Motor Vehicle Volumes: 6,000 ADT on each street
Bikeway Type: One-way protected bike lanes
Corner Refuge Island Outside Radius: 15 feet (4.5 meters)
Setback Distance: 19-22 feet (5.7-6.7 meters)
Note: This intersection was designed as a part of two 5-lane to 3-lane conversions. Existing drainage and curbs were preserved.

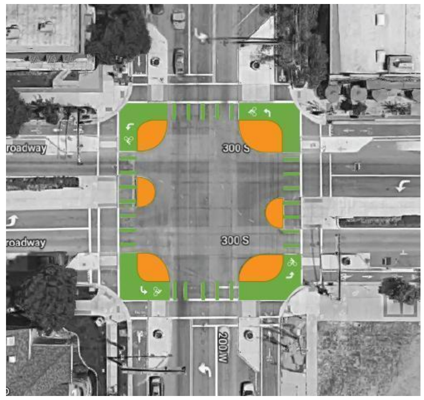

Figure 4.15 Salt Lake City Protected Intersection: Design Elements
Orange: corner refuge and channelizing islands, green: bike lanes
(Aerial view source: Google Maps)

Figure 4.16 Salt Lake City Protected Intersection: Travel Modes Separation
Left: sidewalk and walking directions
Middle: bike lanes and bicycling directions
Right: automobile lanes and automobile directions
(Aerial view source: Google Maps)

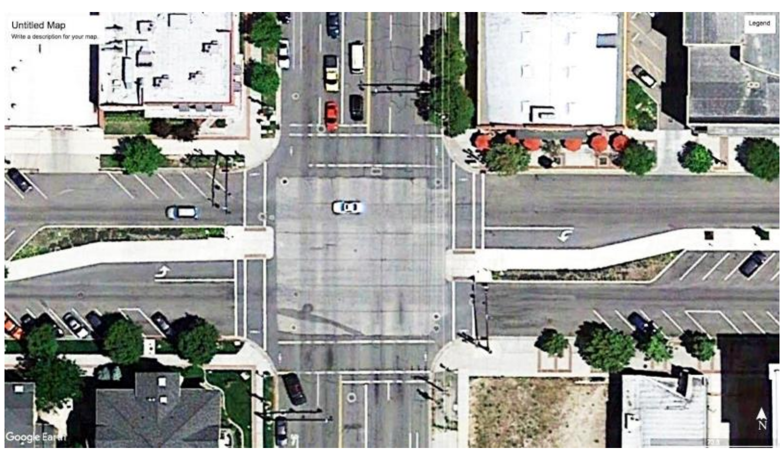

Figure 4.17 Salt Lake City Protected Intersection: Pre-Implementation
(Source: Google Maps)

Figure 4.18 Salt Lake City Protected Intersection: Post-Implementation
(Source: Google Maps)

5.0 METHODOLOGY

5.1 Overview

This study employs a before-and-after case study. While there have been studies on new treatments of bicycle-friendly infrastructure (Allen and Harper, 2005; Wall, Davies, and Crabtree, 2003), the literature focuses on European cases that show a relatively greater bicycle use and rarely examines cases in the U.S. context (Korve and Niemeier, 2002). Salt Lake City's 200 West/300 South intersection is the best example of the modern protected intersection design among those that exist in a handful of U.S cities.[6] Thus, a longitudinal analysis of this example will help researchers and practitioners to better understand the effects of intersection design changes in the U.S. context. Although there may be concern about generalizing from individual cases, as Flybvjerg (2006) noted, an in-depth understanding of best practices and their contexts can contribute to creating a more concrete and practical knowledge.

5.2 Quantitative Video Review

The first section of the analysis focuses on quantitative changes from before and after the new intersection design was implemented. The quantitative changes include two parts:

Changes in Volume: We identified how many people use the intersection and how the numbers have changed since the new intersection was introduced. We counted the number of people walking, bicycling, and using other devices (scooters, skateboards, Segways, etc.) approaching or crossing the intersection every hour.

Changes in Behaviors: We examined whether the rates of non-optimal behaviors have changed since the new intersection was introduced. We counted the total number of non-optimal behaviors of people walking, bicycling, and using other devices at the intersection.[7]

---

[6] As of 2015, there were only four protected intersections in the U.S.—Salt Lake City, Chicago, Austin, and Davis (Source: Alta Planning +Design, 2015), but this number has increased since then.

[7] Although automobiles are an important travel mode to consider when determining the safety of a protected intersection, we did not include this mode because of the limitations of observation method using video data and poor data reliability, compared to the other data. An alternative way to consider automobiles in this study would be reviewing crash data, but because of the small number of incidents and the difficulty of determining if a crash

5.2.1 Video Data and Analysis

Video records showing 36 hours of intersection users were obtained from the Salt Lake City Transportation Division. As shown in Figure 5.1, these data come from 12-hour segments taken on three separate days: July 31, 2015 (before), August 19, 2016 (after 1), and August 24, 2018 (after 2). Each video was recorded under particular controlled conditions -- taken for 12 hours (7 a.m. to 7 p.m.) at the same place, on the same day of the week (Friday), in the same time of the year (July or August), and in similar weather conditions. One limitation of the data is slightly different shooting frames between the videos, making it difficult to observe some people approaching the intersection in the July 31 video, which may result in underestimated counts.

We broke video analysis into three separate tasks. First, we counted intersection users, segmenting counts by mode of travel. We ran the video at a faster than real-time speed to expedite the analysis. We analyzed all 12 hours of video for each day, and recorded counts by the hour. The next two tasks consisted of identifying non-optimal behaviors. We analyzed non-optimal behaviors of non-motorized and motorized modes separately, as the different speeds of these two groups did not allow for concurrent analysis. This required running the video at near real-time playback speeds with frequent pausing and rewinding to ensure that behaviors were identified correctly, and nothing was missed. Because this process was so time intensive, we sampled three one-hour segments (9-10 a.m., 1-2 p.m., and 5-6 p.m.) for each observation day.

Figure 5.1 Screenshots of Video Records (Source: Google Maps)

incident is associated with intersection design, the vehicle collision information was also dropped. This is a critical caveat and the principal reason why this study focuses on behavioral analysis and not safety.

5.2.2 Types of Non-Optimal Behaviors

Although counting the number of intersection users is quite straightforward, as noted in the previous section, identifying and counting non-optimal behaviors can be somewhat subjective. Thus, to increase the precision of the work, a pilot study was conducted and, based on the pilot study, we defined optimal and non-optimal behaviors. Optimal behavior refers to walking, riding a bike, and driving a car in a given lane in a correct direction in accordance with traffic signals (Figure 5.2). Non-optimal behaviors are defined as any behaviors that deviate from the optimal behaviors.

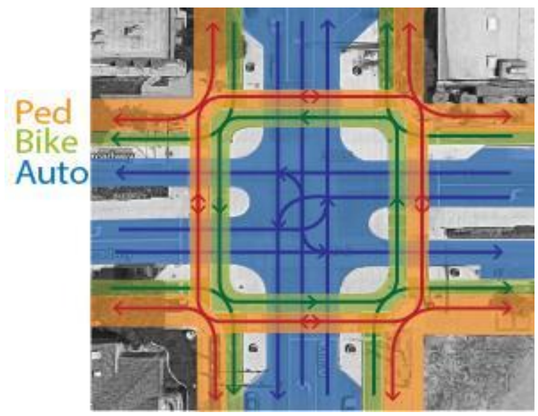

Figure 5.2 Optimal Behaviors at the Protected Intersection

As a result of the pilot study, a total of 19 non-optimal behaviors were identified: seven for people bicycling, five for people walking, and seven for other users (Table 5.1). First, as each user approached the intersection, we examined the number of users moving outside the correct lanes. Second, as each user turned or crossed the intersection, we counted the number of users crossing outside the correct crossing lanes, disobeying signals, or riding a bike in the opposite direction. Lastly, as each user stopped at the intersection, we investigated the number of users that were in wrong places.

Table 5.1 Types of Non-Optimal Behaviors

Mode	Behavior group	Non-optimal behavior	Description
Bicycling	Approaching	Riding on sidewalk*	Bicycle riding at least 15 ft. in sidewalk
		Riding on street*	Bicycle riding at least 15 ft. along the roadway, except crossing on street
	Turning / Crossing	Clockwise riding/wrong direction in intersection*	Bicycle riding/turning in a wrong direction in bike lane
		Crossing in crosswalk	Bicycle crossing in any direction in crosswalk
		Crossing in street*	Bicycle turning in street (exposed and non-protected area) (e.g., riding roadways at intersection)
		Disobeying signal*	Bicycle crossing intersection against car movement
	Stopping	Stopping in wrong place*	Bicycle stopping in sidewalk, roadway, and other places that are not a bike lane
Walking	Approaching	Walking on street*	Pedestrian walking at least 15 ft. along the roadway, except crossing on street
		Walking on bike lane*	Pedestrian walking at least 15 ft. on the bike lanes, except crossing the intersection)
	Turning / Crossing	Crossing outside crosswalk*	Pedestrian crossing in roadway and bike lane
		Disobeying signal*	Pedestrian crossing intersection against the “Don’t Walk” (or Red Hand) signal
	Stopping	Stopping in wrong place*	Pedestrian stopping in roadway and/or bike lane
Others (e.g., scooter, skateboard, Segway users)	Approaching	Riding on sidewalk	Other using at least 15 ft. in sidewalk
		Riding on street	Other using at least 15 ft. along the roadway, except crossing on street
	Turning / Crossing	Clockwise riding/wrong direction in intersection	Others turning in a wrong direction in bike lane
		Crossing in crosswalk	Others turning any direction in crosswalk
		Crossing in street	Others turning in street (exposed and not-protected area) (e.g., riding roadways at intersection)
		Disobeying signal	Others crossing an intersection against cars movement
	Stopping	Stopping in wrong place	Others stopping in sidewalk or roadway

*An example video screenshot is presented below

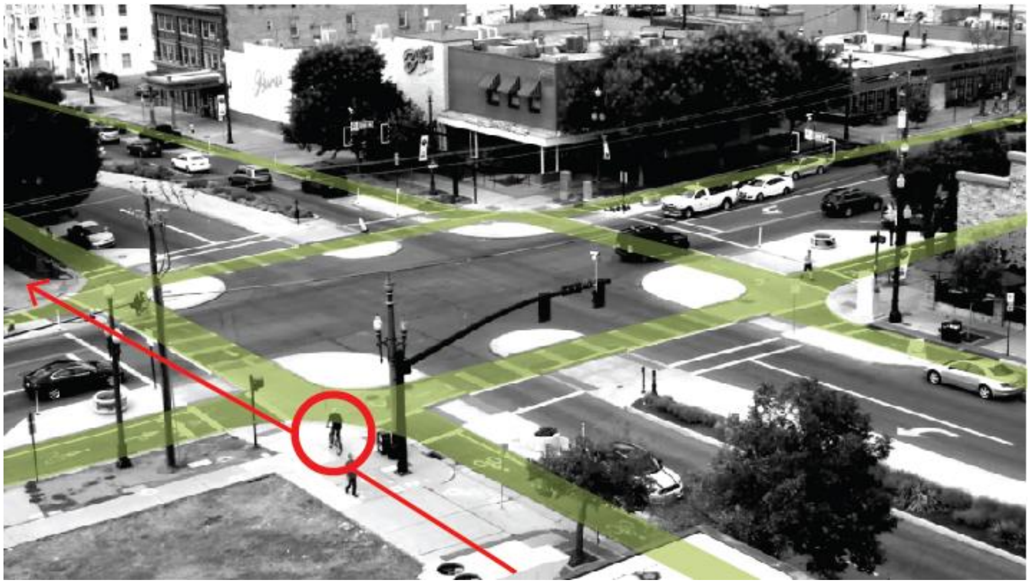

Figure 5.3 Bicycle: Riding on Sidewalk

A person bicycling approached the intersection on the sidewalk and kept riding on the sidewalk after crossing the intersection.

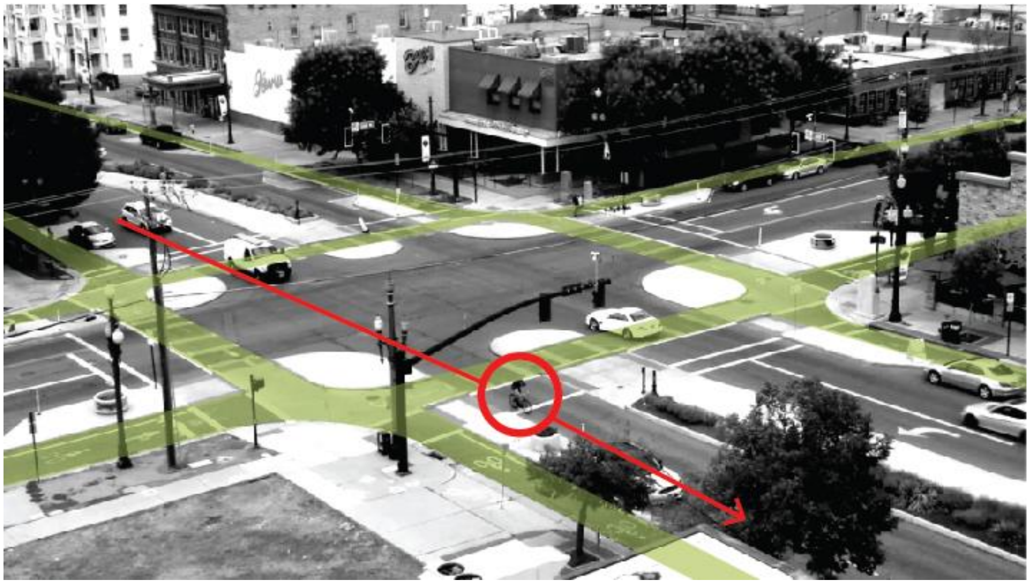

Figure 5.4 Bicycle: Riding on Street

A person bicycling crossed the intersection on the road despite the close proximity of the bike lane.

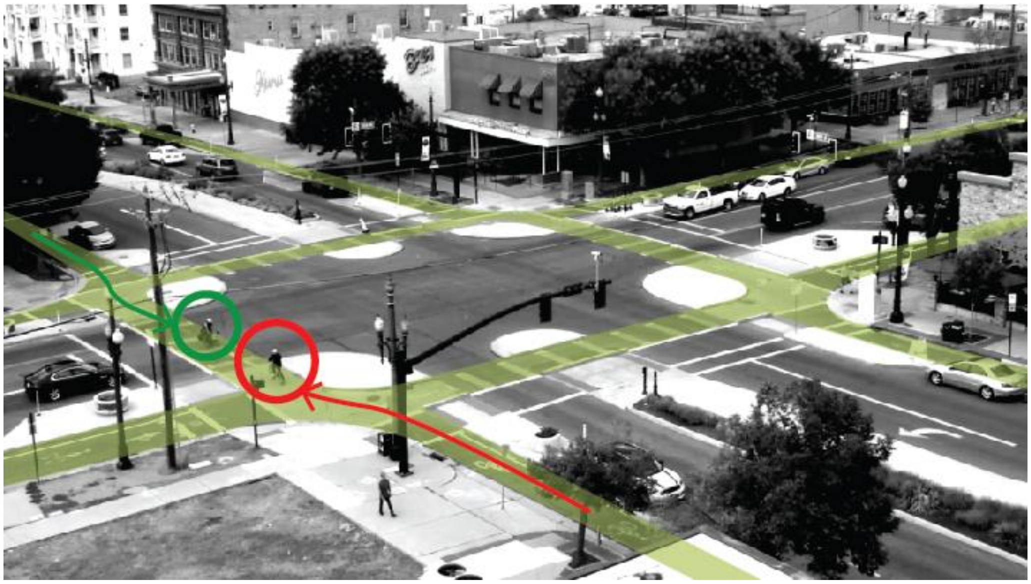

Figure 5.5 Bicycle: Clockwise-Riding/Wrong Direction in Intersection

A person bicycling rides in the bike lane in a clockwise direction against the intended traffic flow.

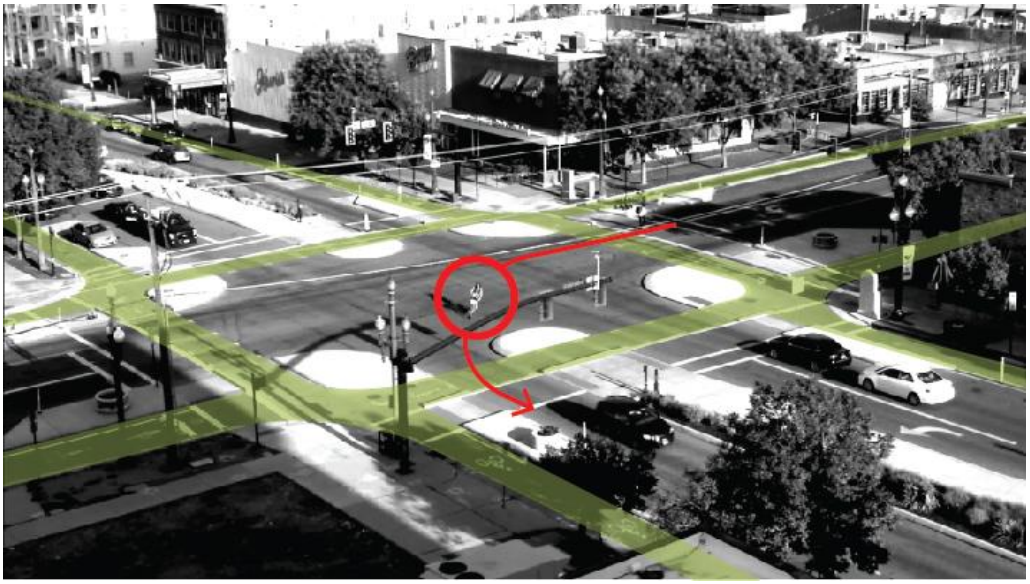

Figure 5.6 Bicycle: Crossing in Street

After riding a bike on the road, a person bicycling continued to use the roadway when turning left at the intersection.

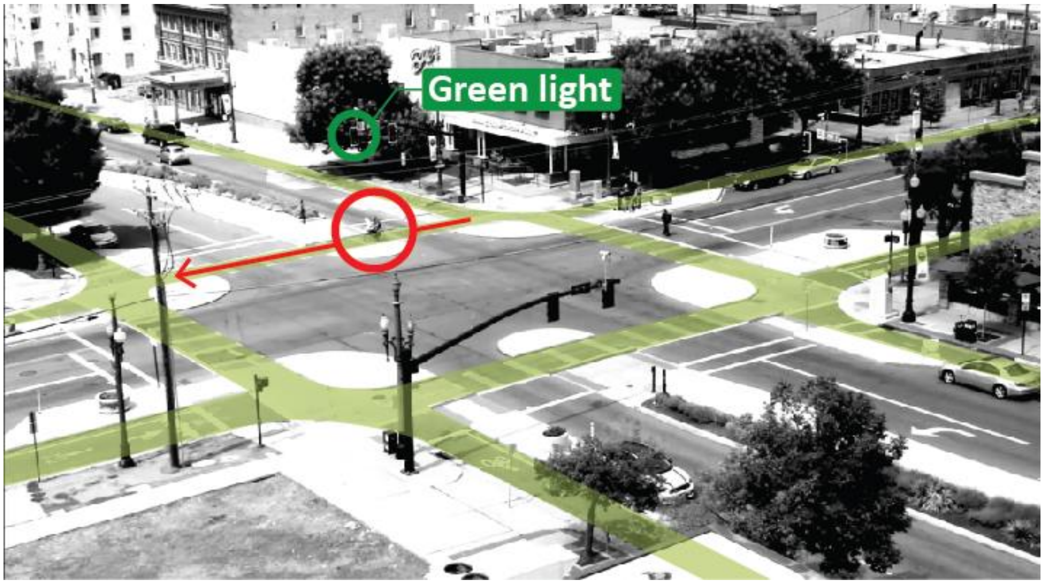

Figure 5.7 Bicycle: Disobeying Signal

After checking if there are cars on the road, a person bicycling crosses the intersection against a red light.

Figure 5.8 Bicycle: Stopping in Wrong Place

The above image depicts a person bicycling waiting to cross the intersection stopped at the sidewalk ramp, which may cause conflicts with people walking.

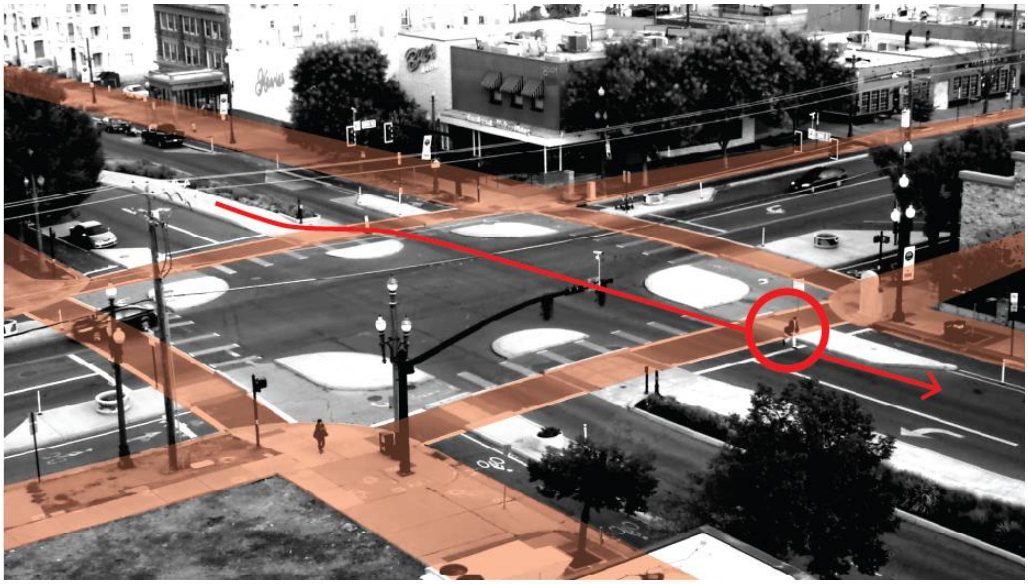

Figure 5.9 Pedestrian: Walking on Street

A person walking has made an illegal movement by crossing the intersection on the roadway.

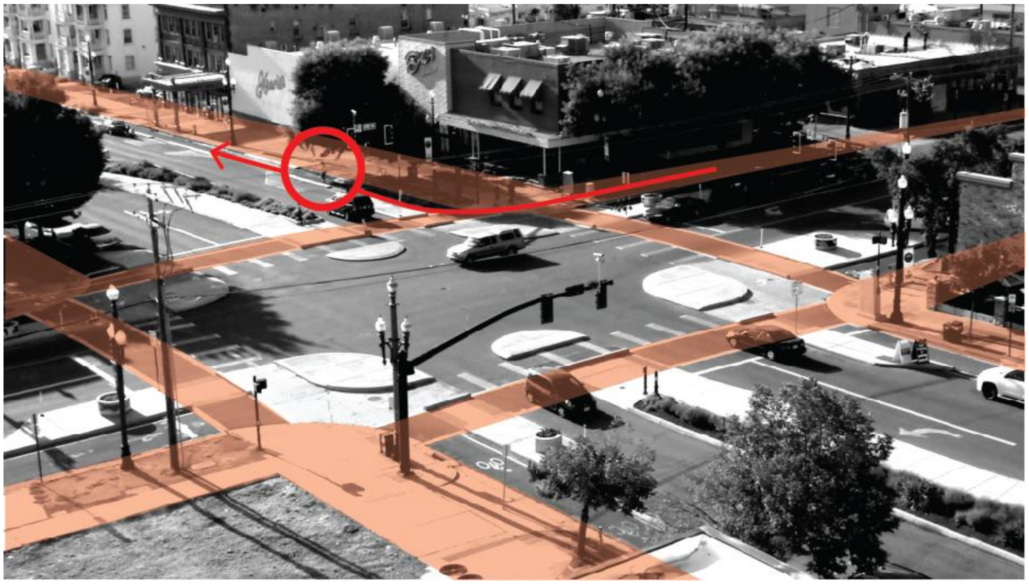

Figure 5.10 Pedestrian: Walking on Bike Lane

After turning right at the intersection, a person walking left the sidewalk and continued walking in the bike lane.

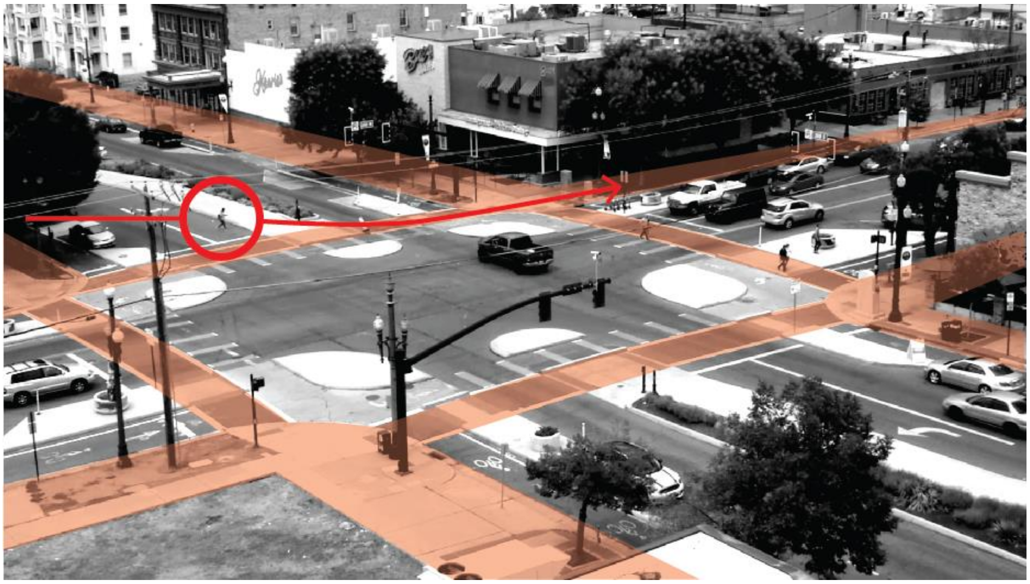

Figure 5.11 Pedestrian: Crossing Outside Crosswalk

A person walking crossed the intersection on the road, not on the marked pedestrian crosswalk.

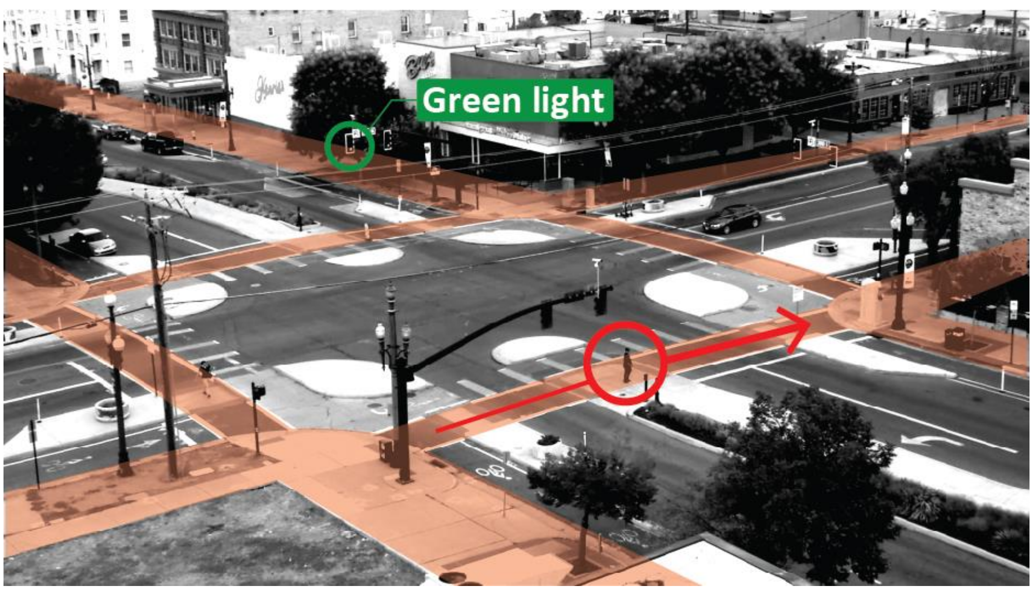

Figure 5.12 Pedestrian: Disobeying Signal

A person walking is crossing the intersection against the indication of the traffic signal.

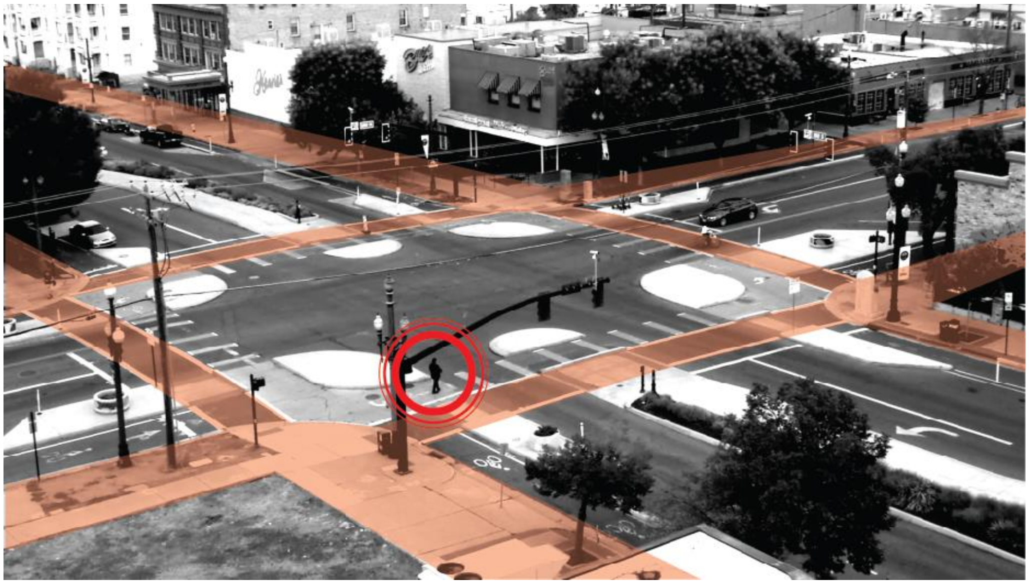

Figure 5.13 Pedestrian: Stopping in Wrong Place

A person walking waits to cross the intersection while stopped in the bike lane, which may lead to conflicts with people bicycling.

5.2.3 Reliability of Observation

We tested inter-rater reliability, also called inter-observer reliability or inter-rater agreement, for two types of data: 1) total counts by transportation mode and 2) counts by each non-optimal behavior type. Intraclass correlation coefficient (ICC) is an appropriate measure of inter-rater reliability and has been used in behavioral research (Hallgren, 2012; Koo and Li, 2016; Shrout and Fleiss, 1979). ICC measures the extent of agreement between two or more raters for continuous variables. Higher ICC values indicate greater reliability, with an ICC estimate of 1 indicating perfect agreement, 0 indicating only random agreement, and negative ICC indicating systematic disagreement.

According to Cicchetti (1994), inter-rater reliability should be considered poor for ICC values less than 0.40, moderate for values between 0.40 and 0.59, good for values between 0.60 and 0.74, and excellent for values greater than 0.75. Following the guideline from Koo and Li (2016), we used a “two-way mixed model”, because raters are fixed, subjects are chosen randomly, and “absolute agreement” was measured rather than consistency. The ICC values were computed in R 3.6.0 software (psych package).

A fifteen-minute video segment was used as a unit of analysis for the reliability test. Minimum sample size for three raters with ICC 0.5 minimum, power 80%, and alpha 0.05 is 11 (Bujang and Baharum, 2017). Thus, three observers watched the same 11 fifteen-minute video segments and counted people bicycling, people, and others using other means (scooters, skateboarders, Segway users, etc.) for each non-optimal behavior type.

Table 5.2 shows that the inter-rater reliability of total counts is excellent for all active transportation modes in the observed intersection. Table 5.3 also illustrates that the reliability of non-optimal behaviors is considered excellent by mode with the ICC values from 0.84 for pedestrian to 0.94 for other users (scooter users, etc.), but there are greater differences in reliability by behavior type. When coded by each behavior type, 18 of the 19 categories had one or more incidences in the sample video clips; one category— “other modes crossing in street”— was not observed by any rater, as it was rarely found in our observation result. Out of 19 categories, 10 categories are considered in excellent reliability range (ICC > 0.75), three in good reliability range (0.60 < ICC < 0.75), and four in fair range (0.40 < ICC < 0.60). One category that reported a poor ICC value (less than 0.40) is “bicycle stopping in wrong place” (ICC = 0.32). Thus, data for these low-reliability categories would need a careful interpretation.

Table 5.2 Inter-Rater Reliability Test Results of Total Counts by Transportation Mode

Category	Average number of people per hour			ICC
	Rater1	Rater2	Rater3	
Bicycling	37.78	32.67	37.69	0.85
Walking	203.06	189.08	200.97	0.95
Other (Scooter)	11.47	11.33	9.86	0.99
Total	252.31	233.08	248.53	0.95

Table 5.3 Inter-Rater Reliability Test Results of Counts by Non-Optimal Behavior

Mode	Behavior group	Non-optimal behavior	ICC (by mode)	ICC (by behavior type)
Bicycling	Approaching	Riding on sidewalk	0.91	0.87
		Riding on street		0.84
	Turning / Crossing	Clockwise riding/wrong direction in intersection		0.60
		Crossing in crosswalk		0.94
		Crossing in street		0.62
		Disobeying signal		0.62
	Stopping	Stopping in wrong place		0.32
Walking	Approaching	Walking on street	0.84	0.49
		Walking on bike lane		0.50
	Turning / Crossing	Crossing outside crosswalk		0.78
		Disobeying signal		0.83
	Stopping	Stopping in wrong place		0.43
Others (e.g., scooter, skateboard, Segway users)	Approaching	Riding on sidewalk	0.94	0.93
		Riding on street		0.50
	Turning / Crossing	Clockwise riding/wrong direction in intersection		0.88
		Crossing in crosswalk		0.87
		Crossing in street		NA
		Disobeying signal		0.98
	Stopping	Stopping in wrong place		0.81

5.3 Interviewing

The second part of our study analyzes experiences and perceptions of local business owners or managers with respect to the protected intersection. These interviews dove deeper to better understand how business owners perceived the protected intersection, and how they believed the infrastructure affected their business before, during, and after the construction of the intersection. We asked participants about concerns over parking, traffic, and other frequently-referenced issues that were raised in the initial pre-implementation survey.[8] The interviews add a

[8] The initial surveys of eight restaurant owners or managers having a business near the intersection were conducted in January 2015. The participants were asked whether they favored the protected intersection concept and detailed reasons for it. The survey results showed that seven out of eight participants were favorable to the new intersection design concept, even though there were few concerns discussed during the survey, while one was indifferent. The

layer of nuance to our quantitative data, allowing us to triangulate the results of the entire inquiry.

5.3.1 Interview Questions

We designed a semi-structured interview. Interview questions were organized into the following three categories. First, we asked the interview participants about their thoughts on the new intersection configuration before it was implemented. We expected that this question would help us to understand their previous concerns/expectations regarding the new intersection. The second question related to participants' experience in the process of public engagement and intersection construction in 2015. Lastly, we touched on changes in their perceptions and the various impacts on their business as a result of the new configuration post-implementation. We identified concerns of local businesses over on-street and valet parking, traffic congestion, bicycling and walking, and others from a preliminary survey, among others. The predetermined questions are listed below.

Before:

- Did you have any concerns/expectations about the protected intersection before it was constructed?

During:

- How was your experience with the public engagement process?

After:

- Has your opinion of the intersection changed at all since the intersection has been implemented?
- How do you feel the intersection has affected business, if at all?
- Have you noticed any changes to the immediate area that you think are attributable to the intersection? (traffic, parking, bike/ped activity)
- Would you change anything about the intersection?
- Have you experienced more or less traffic congestion since the implementation?

---

reasons for their support of the intersection included "better for bikes", "the possibility of an additional parking space", "the potential to reduce confusion at the intersection", "easier valet parking", and "angled parking", whereas they also showed concerns over "traffic congestion keeping customers away" and "parking loss on 200 West."

- Have you experienced or heard of any issue regarding safety from people walking, bicycling, or driving after the implementation?
- How would you rank your opinion of the intersection from unfavorable to highly favorable? (Likert Scale –1 2 3 4 5 6 7)

5.3.2 Interviewees

Interview participants were selected among the business owners or managers that are most likely to be affected by the intersection design change. We selected and contacted eight candidate interviewees who have a business in the distance of a half-block-face (approximately 400 feet from the intersection); however, only three of them agreed to participate in the interview. Pre-implementation interviews were conducted by the City in January 2015, and we used these contacts as our primary source for potential participants. The majority of businesses immediately proximal to the intersection are restaurants, and our sample is relatively representative of this mix (100% restaurants).

Figure 5.14 Candidate Interviewee Geography

5.3.3 Interview Protocols

We conducted semi-structured interviews in order to maintain relative consistency among the data obtained from each interview. As is typical of this type of qualitative data collection process, we followed up with additional clarifying questions as the conversations warranted. After the topics were sufficiently discussed with interview subjects, the interviewer synthesized and reported back to the interviewee what he had gathered and recorded (by typing) from the previous exchange. We did not record interviews in order to keep interview subjects at ease and allow for more candid conversations to occur. We synthesized the answers of our interviewees in order to confirm that we adequately understood the points of the interviewee and did not miss any important data. Interviews typically took around an hour and some follow-up email exchanges helped to fill any gaps in the data.

6.0 RESULTS

6.1 Intersection Usage

Table 6.1 displays changes to intersection usage as estimated by video data counts of different non-automobile modes. We calculate change as the difference between the average of the two post-implementation sample periods (2016 and 2018) and the pre-implementation period (2015). The exception to this method is the calculation of change in the scooter category, which is measured as the difference between the average of the two days of video (August 2015 and 2016) before the deployment of shareable e-scooters in the summer of 2018 and the video in August 2018 that was filmed after shareable e-scooters were deployed.

In Salt Lake City, e-scooter sharing systems were introduced in 2018, and as of October 2019 there were four scooter companies: Bird, Lime, Razor, and Spin. Although the 2018 data showed an early pilot stage of scooter usage in Salt Lake City, the big growth that occurred later was observed to occur without a significant decrease in the other active transportation mode usages. This seems to indicate that e-scooters have increased total active transportation usage.

In total, we found an increase of 157 additional non-motorized users of the intersection after the implementation of the new protected intersection configuration, per the two days of video data analyzed. This is a modest increase, with the greatest growth in usage happening between 2016 and 2018. Interestingly, we see little change in bicycling and walking usage from before and after the implementation of the protected intersection. Most notably, almost all the growth in active transportation usage of the protected intersection between 2016 and 2018 is attributable to the increase in e-scooters. This mode demonstrates 337 more scooters since 2016 (Table 6.2).

Table 6.1 Intersection Usage

Mode	Hour	2015	2016	2018	Change
Bicycling	**Total**	**431**	**457**	**409**	**1.8**
	7-8am	22	36	36	13.7
	8-9am	28	42	29	7.3
	9-10am	29	32	25	-0.7
	10-11am	24	26	18	-1.7
	11-12am	24	45	31	13.8
	12-1pm	41	39	33	-5.5
	1-2pm	30	27	35	1.3
	2-3pm	40	27	38	-7.7
	3-4pm	41	49	41	4.0
	4-5pm	54	51	54	-1.8
	5-6pm	75	47	33	-35.3
	6-7pm	22	36	36	14.3
Walking	**Total**	**2,379**	**2,327**	**2,412**	**-9.3**
	7-8am	123	87	94	-32.7
	8-9am	128	134	116	-3.5
	9-10am	91	96	79	-3.2
	10-11am	113	97	96	-16.3
	11-12am	181	164	206	4.0
	12-1pm	229	256	255	26.5
	1-2pm	286	238	249	-42.5
	2-3pm	178	183	181	4.0
	3-4pm	182	192	214	20.7
	4-5pm	230	214	246	0.0
	5-6pm	335	289	298	-41.2
	6-7pm	302	376	378	74.8
Other	**Total**	**21**	**21**	**350**	**164.5**
	7-8am	2	1	4	0.7
	8-9am	1	1	8	2.8
	9-10am	0	1	13	6.7
	10-11am	0	1	11	5.8
	11-12am	2	1	24	10.8
	12-1pm	1	1	55	27.0
	1-2pm	2	3	39	19.0
	2-3pm	2	3	31	15.3
	3-4pm	2	3	38	18.2
	4-5pm	4	2	40	16.7
	5-6pm	3	1	42	18.3
	6-7pm	1	2	47	23.2
Total		**2,831**	**2,805**	**3,171**	**157**

Note: The data come from 12-hour segments, one day each year. All counts are averages using data assessed by three observers. All numbers in the Change column show the difference between 2015 and the average of 2016-2018 in order to show the before/after change related to the implementation of the protected intersection.

Table 6.2 Intersection Usage: Scooter Only

Mode	Hour	2015	2016	2018	Change
Other (Scooters only)		**5**	**2**	**339**	**335.8**
	7-8am	0	0	3	2.3
	8-9am	1	0	5	5.0
	9-10am	0	1	12	12.0
	10-11am	0	0	10	10.0
	11-12am	1	0	24	23.3
	12-1pm	0	0	55	54.7
	1-2pm	0	0	39	38.5
	2-3pm	0	1	29	28.7
	3-4pm	0	0	38	37.8
	4-5pm	0	0	38	38.2
	5-6pm	1	0	40	39.7
	6-7pm	1	0	46	45.7

Note: The Change column shows the change between the average of 2015-2016 and 2018 because e-scooter-sharing systems began in 2018.

6.2 Non-Optimal Behavior

Table 6.3 displays measures of non-optimal behavior among all active transportation modes. To calculate the rate of non-optimal behaviors, we divided the counts of behaviors by the estimated usage counts. We recorded the travel-mode volume estimates by the hour, so the volumes were aggregated into peak-hour segments (9:00-10:00 am, 1:00-2:00 pm, and 5:00-6:00 pm), corresponding with our non-optimal behavior sample times. Some patterns can be observed in non-optimal behaviors among people bicycling after the implementation of the protected intersection. People bicycling across the intersection in the crosswalk declined from a pre-implementation rate of 17.1% to a post-implementation average of 6.2%. This may be due to the improved painted pavement that makes the bicycling area much clearer than in the previous configuration. People bicycling also demonstrated a decrease in the rates of exposed left turns after the implementation of the protected intersection. This came as somewhat of a surprise, as we expected the optimal movement for a left turn, which requires that a person bicycling ride straight across the intersection then wait for another signal change, then travel straight across again, may be too onerous to elicit an observable change even with the new configuration. This was not the case, however, and the rate of exposed left turns declined from 17.1% to an average of 2.5%.

Table 6.3 Non-Optimal Behavior

Behavior			2015	2016	2018
Traveler	**Behavior group**	**Non-Optimal behavior**		**per user %**	
Bicycling	Approaching	Riding on sidewalk	11.7	8.0	12.2
		Riding on street	7.2	5.6	7.8
	Turning / Crossing	Clockwise riding/wrong direction in intersection	5.4	10.4	7.8
		Crossing in crosswalk	17.1	7.2	5.2
		Crossing in street	17.1	2.4	2.6
		Disobeying signal	5.4	8.0	12.2
	Stopping	Stopping in wrong place*	16.2	3.2	2.6
Walking	Approaching	Walking on street	0.3	0.2	0.6
		Walking on bike lane	0.0	0.3	0.5
	Turning / Crossing	Crossing outside crosswalk	6.1	2.1	5.6
		Disobeying signal	9.6	9.2	11.6
	Stopping	Stopping in wrong place	3.1	0.0	0.9
Other (e.g., scooter, skateboard, Segway users)	Approaching	Riding on sidewalk	--	--	43.2
		Riding on street	--	--	5.3
	Turning / Crossing	Clockwise riding/wrong direction in intersection	--	--	12.6
		Crossing in crosswalk	--	--	22.1
		Crossing in street	--	--	3.2
		Disobeying signal	--	--	16.8
	Stopping	Stopping in wrong place	--	--	4.2

Note: The data come from three one-hour segments (9:00-10:00 am, 1:00-2:00 pm, and 5:00-6:00 pm), in each of the three counts. All numbers were reported by one observer who used a reliable observation protocol. We do not report non-optimal behaviors rates for the "other" category prior to the 2018 observation because the small number of observations contributed to misleading measures. However, the value of 2018 "Other" data is found to make a comparison with non-optimal bicycling behaviors. An asterisk mark (*) indicates non-optimal behaviors with a poor ICC value.

People bicycling also demonstrated lower rates of stopping in incorrect positions after the implementation of the protected intersection. We might attribute this improvement to the clearer delineation of space for stopped bicyclists in an area known between the forward stop bar (ahead) and the perpendicular street's protected bike lane (behind), and between the corner refuge island (left) and the concrete separation between bike lane crossing and crosswalk (right). However, as noted earlier, this category showed a low ICC value, so the results can be greatly different by observer. This area is painted a different color (FHWA-approved green) than the other pavement and is also physically separated from the street, likely leading to an increased feeling of comfort and predictability for people bicycling waiting for the traffic signal to change. There was one non-optimal behavior that increased significantly after the protected intersection was implemented: people bicycling not obeying the signal and crossing against the movement of cross-street traffic. This presents potential safety concerns as people bicycling are vulnerable to being hit from the side by a car traveling perpendicular to the direction of their travel. We suggest that this change is likely due to the reduction in travel lanes and thus the shorter distance the person bicycling must traverse across the intersection while being exposed to motorized traffic.

The behavior of people walking did not change in a way that provided many observable patterns. The changes in non-optimal behavior of this mode were small and did not seem to fluctuate in a way that reflected an impact of the protected intersection on pedestrian movements. One exception is the decrease in the rate of crossing outside crosswalk (6.1% to 3.9%). We hypothesize that a clear delineation between a pedestrian crosswalk and a bike lane may encourage both people walking and people bicycling to stay in their rights-of-way.

As we discuss above in reporting changes in usage of the intersection over the study period, the arrival of e-scooters to Salt Lake City in June 2018 led to changes in the way the protected intersection was utilized. We do not report figures for the "Other" category prior to the 2018 observation because the small number of observations contributed to misleading measures. For this reason, we will simply compare 2018 observations of e-scooter users' non-optimal behavior to 2018 behavior of people bicycling. We make this comparison because existing regulations about where e-scooters can travel are typically similar to those that apply to bicycles.

We see that e-scooters display higher rates of non-optimal behavior in every category with the exception of riding in the roadway[9]. E-scooters also demonstrate similar, but slightly higher rates of making exposed left turns and stopping out of place. E-scooter users are much

[9] There is difficulty in defining non-optimal behaviors of e-scooters because this shared mobility is recently adopted and how to regulate e-scooters is an ongoing discussion in academia. Based on the current Salt Lake City regulations for e-scooters (https://www.slc.gov/transportation/sharedmobility/), riding a scooter in street is allowed. However, the protected intersection was designed to separate different travel modes, and e-scooters are most similar to bicycles in terms of speed, so in this study, we used the non-optimal behavior categories of bicycles for e-scooters.

more likely to disobey the signal compared to their bicycling counterparts, with 16.8% of users crossing against cars' movement. The non-optimal behavior that e-scooter users are most likely to exhibit is riding on sidewalks. A total of 43.2% of all observed e-scooter users were riding on sidewalks instead of the protected bicycle lanes or in the roadway, where they are expected to operate. Similarly, e-scooter riders also crossed the intersection within the crosswalk instead of crossing in the bicycle lane at a rate of 22.1%, compared to bicycle users' 5.1%.

6.3 Interview Results

Our qualitative analysis produced a relative consensus among our interview participants. Below, we will highlight important observations and comments, as determined by our analysis of interview data. We break the results down into sections including pre-implementation, construction and public engagement, and post-implementation. Responses are synthesized, except for elucidative quotes which will be highlighted.

6.3.1 Pre-Implementation

Generally, the business representatives that we spoke to expressed that they had had little concern about the project leading up to its implementation, with a few exceptions. Primarily, the main concerns that businesses had prior to the implementation of the intersection were related to reductions in parking availability, specific configuration issues, and the potential for the intersection to increase traffic congestion on the street. The concerns of our interview respondents were in line with the feedback that was received by the city in their public engagement process before and during the project was implemented, although the anxiety that was noted in the previous engagement process seemed more muted among our respondents in 2019. One respondent reported that the owner of the restaurant had been openly opposed to the intersection configuration, but this view did not reflect that of the interviewee. Specific configuration concerns included the location of curb cuts and driveway access, location and number of on-street parking stalls, and signage placement.

6.3.2 Construction and Public Engagement

Again, our respondents did not express any major concerns with respect to the public engagement or construction process. While two of our three respondents, in fact, had little to say about it, one respondent commented that they had a very pleasant experience working with the City throughout the engagement process. They went on to say:

> *"The City was great to work with. They were super responsive and [City employee] was super attentive to my input, although my suggestions were not implemented in the end. I feel like either they were effectively placating me or my suggestions were not ultimately feasible."*

Other respondents admitted that they were not particularly invested in the public engagement process.

6.3.3 Post-Implementation

Our questions related to business representatives' post-implementation perspectives of the intersection were more numerous as well as more attended to by our interviewees. One of the most important questions we asked was how the intersection affected the businesses of our interviewees. Responses to this question ranged from being unable to assess to positive. One participant reported that the intersection had negatively affected their business by making valet service more difficult and sometimes decreasing perceived safety for their clients, while at the same time positively affecting business by enhancing the walkability and pedestrian appeal of the immediate area. Another participant was more bullish in their assessment of how the intersection had affected business:

> *"[The protected intersection] has had a positive impact. Cars used to go fast through here, but now they have to slow down. I feel like they can actually notice [our business] now. It's made the street more walkable and that helps too."*

The above statement positively counteracts one of the common concerns that business representatives expressed prior to the intersection's construction, which was the potential impacts on traffic congestion. All our participants agreed that the new configuration had restrained the flow of traffic, leading to some perceived backup as well as perceived slower travel speeds. Surprisingly, however, they also agreed that this had actually been a benefit, contrary to their initial positions. One participant explained that the perceived reduction in ease of throughput of the intersection, they believed, was being adequately handled by these and nearby, parallel and perpendicular streets. They went on to assert that alternating walking- and bicycling-focused streets in an urban context seemed like a viable pattern if the City were to continue with infrastructure projects such as the protected bicycle lanes and protected intersections. All of the business representatives expressed that they felt that the slower traffic speeds and improved environment for people walking and bicycling were positive outcomes of the intersection implementation that were beneficial to their establishments. One participant told us of their perception of traffic on the street since the intersection's implementation:

> *"[Through-] traffic has decreased on the street. Vehicles try to avoid it. The traffic that was there before wasn't doing anything for the business anyway."*

This response mirrors what was expressed by other respondents: that vehicle traffic on the street had not necessarily been beneficial for businesses prior to the intersection implementation, and the reduction in through traffic and slower vehicle speeds are only making the environment more appealing for people walking. The business representatives in our sample believe that the improved walking environment that has resulted is better for their businesses.

While interview participants reported that their businesses were, at least in some part, positively affected by the new intersection configuration, each respondent was eager to share what they would change about the intersection if they had the chance to do so. Not one of our participants was entirely happy with all the specific elements of the treatment, and they had a lot to say about how they would make it better. Comments ranged from concerns about the placement of cuts in the curb that physically separate the bike lane from the roadway, to the placement of signage, overall awareness of intersection users about the proper usage of the space, and more. Below we will give credence to common complaints and those that were made most insistently by our interviewees.

One of our participants expressed that the general design of physically separating the bicycle lane from the roadway leads to several perceived problems. First, they suggested that snow removal was a problem that was exacerbated by this design, and that their perception was that the bicycle lane was impassible for both people walking and people bicycling that needed to cross it.[10] The business that this interviewee represented relied heavily on valet parking, and they reported many incidents of guests tripping over the separating curb as they exited their vehicles and approached the sidewalk, crossing the bicycle lane in the process. The business representative said that they had made these concerns known to the City, and that the City had addressed the issues with the curb. They also expressed concern regarding the way in which people bicycling behaved within the protected lane. They reported that on many occasions, people bicycling had refused to yield as people walking crossed through the bicycle lane from their vehicles to the sidewalk, nearly causing collisions between the person bicycling and the person walking. The participant added:

> *"[The bicyclists] seem emboldened. Some bicyclists don't feel they need to stop for pedestrians; several guests have almost gotten hit."*

Parking was a consistent concern among our interviewees as well as those contacted by the City in their public engagement process. However, after the protected intersection was constructed, parking was only a direct concern of one participant, and it was indirectly related to the concerns of another. One interviewee remarked that the stalls available for valet parking had been reduced from six to three. They claimed that this reduced the capacity of their valet service during peak times, but they did not believe that the constraint was having any measurable effects on their business. Another interviewee felt that parking had become more confusing for motorists around the protected intersection, but not because of a reduction in the amount of spaces. This business representative felt that the signage, which remained on the sidewalk, had become difficult for drivers to see and interpret. They posited that drivers are used to seeing signage immediately next to parking spaces, and the moving of spaces away from the curbside and,

[10] Note: This statement is based on our interview and the participant perception.

effectively, away from vehicles, made it hard for people parking to understand what they are supposed to do. Additionally, there were concerns regarding opportunities for vehicles to pull into the bicycle lane in places while they parked temporarily to drop off freight or decide where they should ultimately park. One participant was particularly adamant that this was a dangerous situation that would ultimately result in a crash where a motorist blocked the path of an oncoming person bicycling.

A common theme among the concerns of our interviewees was the need for education and outreach regarding how users should most safely utilize the intersection. Most of our participants mentioned a growing uneasiness with the proliferation of e-scooter users and the way that they behave in the protected bicycle lanes, sidewalks, and intersection. One business representative said:

> *"The added element of scooters has made it really dicey. Scooters are making things really dangerous. I'm surprised they haven't been banned yet."*

Those that expressed concerns about e-scooters suggested that this new mode travels too quickly to use either of the active transportation spaces (bicycle lane or sidewalk) and that it simply seems out of place within the existing infrastructure. One interviewee suggested that e-scooters are too unaware of the safe ways to use the intersection, and that education programs need to target these users. They suggested that if additional information were posted at the intersection on each corner, users of all modes that were stopped there might read this information and learn about the proper way to use the space.

7.0 CONCLUSIONS

This paper highlights examples of changes to usage of a protected intersection in Salt Lake City, Utah. We found that after the implementation of a new protected intersection configuration, active transportation usage increased slightly through our three-year study period from 2015 to 2018. Increases in active transportation usage during this time, however, were mostly attributable to a rapid spike in e-scooter users. There has been some speculation among transportation planners and academics whether this new mode might replace trips that would otherwise have been made by walking or bicycling, or whether they are replacing motor vehicle trips, or both. Initial findings from this limited case study suggest that if e-scooters are, in fact, cannibalizing potential walking and bicycling trips, the transfer of trips to e-scooters is not significantly diminishing the number of people bicycling and walking at this protected intersection.

We also analyzed the rates of non-optimal behaviors at the protected intersection, determining how the frequency of these behaviors changed with the implementation of the protected intersection. We found that the behavior of people walking shows a slight change in response to the new configuration: higher rates of people walking were observed staying within the confines of the crosswalk while crossing. More noticeably, the behavior of people bicycling responded to the new infrastructure with reductions in people bicycling crossing within the pedestrian crosswalk, stopping on sidewalks and in the street, and making exposed left turns. The reduction of these non-optimal behaviors suggests a positive effect on perceived safety for people bicycling with the implementation of the protected intersection. Conversely, people bicycling tend to cross against the signal at higher rates with the new configuration.

A new user in the protected intersection space, post-implementation, is the e-scooter rider. These riders demonstrate higher rates of non-optimal behaviors than both people walking and people bicycling. They are more likely to perform all non-optimal behaviors than their counterparts on two feet or bicycles except for making exposed left turns. E-scooter users utilize the sidewalk at an exceptionally high rate when compared to people bicycling, with 43% of all users preferring this space. While we have categorized this as a non-optimal behavior due to Salt Lake City's license agreement guidelines and guidance from regulations emerging around the country, this preference should be considered by planners when deciding how to deal with the proliferation of e-scooters. There may be reasons why e-scooter users prefer to ride on the sidewalk as opposed to the bicycle lane or the roadway. Further research into the reasons for this behavior might elucidate the best ways to plan for and regulate e-scooter use in the future.

Our qualitative analysis shows that businesses express a relatively favorable perception of the protected intersection. Ongoing concerns about the intersection were related to specific design elements, educating users about the appropriate ways to use the intersection, and the interaction between different active modes of transportation. Issues that many businesses expressed prior to the implementation of the intersection, namely reduced parking and increased congestion, did not seem to remain important factors in business representatives' assessment of the intersection.

Generally, this study shows that active transportation use increased after the implementation of a protected intersection in Salt Lake City, Utah. We also show that many non-optimal behaviors were reduced after the new configuration was deployed. This case study gives some evidence that a protected intersection can have positive effects on active transportation volume, compliance to optimal behaviors, and perceived safety in a U.S. context.

However, we must note that this case study does not assert causality related to the observed changes in volumes and behaviors. Although the before-and-after nature of our samples might be a type of quasi-experimental design, the small number of samples—three observation days—limits both the internal and external validity of our findings. Our data does not include analyses on automobile behaviors that should be further examined as the next step to better understand the perceived and real safety of protected intersections. Moreover, all interview results must not be understood as empirically-proved data; they are based on participant perceptions that might include a possibility of conflict with reality. More data and analysis are necessary to begin to make more concrete assertions about the relationships between active transportation volumes, behaviors related to perceived safety, and protected intersection configurations.

REFERENCES

Allen, D., Bygrave, S., & Harper, H. (2005). Behaviour at cycle advanced stop lines (No. PPR240). TRL.

Bassett, David R., John Pucher, Ralph Buehler, Dixie L. Thompson, and Scott E. Crouter. “Walking, Cycling, and Obesity Rates in Europe, North America, and Australia.” Journal of Physical Activity and Health 5, no. 6 (November 2008): 795–814. https://doi.org/10.1123/jpah.5.6.795.

Buehler, Ralph, and John Pucher. “Impacts of Bike Paths and Lanes on Cycling in Large American Cities,” 2011. https://trid.trb.org/view/1091957.

Buehler, R., & Pucher, J. (2012). Cycling to work in 90 large American cities: new evidence on the role of bike paths and lanes. Transportation, 39(2), 409-432.

Buehler, R., & Dill, J. (2016). Bikeway networks: A review of effects on cycling. Transport Reviews, 36(1), 9-27.

California Air Resources Board (2018). California Greenhouse Gas Emissions for 2000 to 2016. 2018 Edition, California Greenhouse Gas Emissions Inventory: 2000-2016

Carter, D. L., Hunter, W. W., Zegeer, C. V., Stewart, J. R., & Huang, H. F. (2006). Pedestrian and bicyclist intersection safety indices (No. FHWA-HRT-06-125).

Cervero, R., Caldwell, B., & Cuellar, J. (2013). Bike-and-ride: build it and they will come. Journal of Public Transportation, 16(4), 5.

Chao, P. J. C., Matthias, J. S., & Anderson, M. R. (1978). Cyclist behavior at signalized intersections. Transportation research record, 683, 34-39.

Cicchetti, D. V. (1994). Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. Psychological assessment, 6(4), 284.

Falbo, Nick (2014). “Protected Intersections for Bicyclists,” n.d., 5.

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. Qualitative inquiry, 12(2), 219-245.

Donna Glassbrenner, United States. National Highway Traffic Safety Administration, National Center for Statistics, Analysis (US), & Westat, Inc. (2002). Safety belt and helmet use in 2002: overall results. National Highway Traffic Safety Administration.

Godefrooij, T. (1997). Rediscovering the bicycle: strategy for a new mobility. In International bicycle planning conference (pp. 5-7).

Gotschi, T. (2011). Costs and benefits of bicycling investments in Portland, Oregon. Journal of Physical Activity and Health, 8(s1), S49-S58.

Hallgren, K. A. (2012). Computing inter-rater reliability for observational data: an overview and tutorial. Tutorials in quantitative methods for psychology, 8(1), 23.

Hunter, W. W. (2000). Evaluation of innovative bike-box application in Eugene, Oregon. Transportation Research Record, 1705(1), 99-106.

Jacobsen, P. L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. Injury prevention, 9(3), 205-209.

Jakobsson, C. (2004). Motivational and volitional control of private automobile use: The effectiveness of transport policies. GU/PSYK/AVH, (129).

Jensen, S. (2007). Pedestrian and bicyclist level of service on roadway segments. Transportation Research Record: Journal of the Transportation Research Board, (2031), 43-51.

Korve, M. J., & Niemeier, D. A. (2002). Benefit-cost analysis of added bicycle phase at existing signalized intersection. Journal of transportation engineering, 128(1), 40-48.

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. Journal of chiropractic medicine, 15(2), 155-163.

Landis, B., Vattikuti, V., & Brannick, M. (1997). Real-time human perceptions: toward a bicycle level of service. Transportation Research Record: Journal of the Transportation Research Board, (1578), 119-126.

Low, L. (1995). Automobile Restriction Policy in Singapore: The economic disincentive approach. The Wheel Extended.

Macmillan, A., Connor, J., Witten, K., Kearns, R., Rees, D., & Woodward, A. (2014). The societal costs and benefits of commuter bicycling: simulating the effects of specific policies using system dynamics modeling. Environmental health perspectives, 122(4), 335.

McNeil, Nathan, Christopher M. Monsere, and Jennifer Dill. "Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists." Transportation Research Record: Journal of the Transportation Research Board 2520 (January 2015): 132–42. https://doi.org/10.3141/2520-15.

Monsere, Christopher, Jennifer Dill, Nathan McNeil, Kelly J. Clifton, Nick Foster, Tara Goddard, Mathew Berkow et al. "Lessons from the green lanes: Evaluating protected bike lanes in the US." (2014).

Murray, C. J., & Lopez, A. D. (1997). Mortality by cause for eight regions of the world: Global Burden of Disease Study. The lancet, 349(9061), 1269-1276.

National Electronic Injury Surveillance System—All Injury Program Operated by the U.S. Consumer Product Safety Commission. Atlanta, Ga: National Center for Injury Prevention and Control; 2002.

Opiela, K. S., Khasnabis, S., & Datta, T. K. (1980). Determination of the characteristics of bicycle traffic at urban intersections. Transportation Research Record, 743, 30-38.

Pucher, John, and Ralph Buehler. "Making cycling irresistible: lessons from the Netherlands, Denmark and Germany." Transport reviews 28.4 (2008): 495-528.

Pucher, John, and Ralph Buehler. "Cycling for Everyone: Lessons from Europe." Transportation Research Record: Journal of the Transportation Research Board 2074, no. 1 (January 2008): 58–65. https://doi.org/10.3141/2074-08.

Pucher, J., Komanoff, C., & Schimek, P. (1999). Bicycling renaissance in North America?: Recent trends and alternative policies to promote bicycling. Transportation Research Part A: Policy and Practice, 33(7-8), 625-654.

Pucher, J., Dill, J., & Handy, S. (2010). Infrastructure, programs, and policies to increase bicycling: an international review. Preventive medicine, 50, S106-S125.

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: uses in assessing rater reliability. Psychological bulletin, 86(2), 420.

Wall, G. T., Davies, D. G., & Crabtree, M. (2003). Capacity implications of Advanced Stop Lines for cyclists. Transport Research Laboratory.

Wang, Y., & Nihan, N. L. (2004). Estimating the risk of collisions between bicycles and motor vehicles at signalized intersections. Accident Analysis & Prevention, 36(3), 313-321.

Wachtel, A., & Lewiston, D. (1994). Risk factors for bicycle-motor vehicle collisions at intersections. ITE Journal (Institute of Transportation Engineers), 64(9), 30-35.

Webb, C. N. (2018). Motor Vehicle Traffic Crashes as a Leading Cause of Death in the United States, 2015 (No. DOT HS 812 499).

Weigand, L. (2008). A review of literature: Intersection treatments to improve bicycle access and Safety. Portland: Center for Transportation Studies, Portland State University.

Wolfe, M., Fischer, J., Deslauriers, C., Ngai, S., & Bullard, M. (2006). Bike Scramble Signal at N Interstate & Oregon. IBPI Research Digest.